NASA Technical Memorandum 58263

Research and Technology

Annual Report 1984

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National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

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November 1984

Prepared by

Office of the Director of Research and Engineering
Lyndon B. Johnson Space Center
Houston, Texas

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Preface

This report is prepared on an annual basis for the purposes of highlighting the fiscal year research and technology (R&T) activities. Its intent is to better inform the R&T Program Managers of significant accomplishments that promise practical and beneficial program application. The report is not inclusive of all R&T activities. This document will be updated in November of each year.

The JSC Annual R&T Report is compiled by the Office of the Director of Research and Engineering. The personnel listed below have coordinated the technical inputs for their respective sections of the report. Detailed questions may be directed to them or to the technical monitors listed in the Significant Task indices.

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Office of Space Flight

Summary

Introduction

The Office of Space Flight (OSF) Advanced Programs activities are directed toward enhancing and expanding the National Space Transportation System (STS). In fiscal year (FY) 1984, the third Space Shuttle Orbiter, *Discovery*, was added to the STS inventory. The STS Program is approaching a fully operational status as evidenced by many significant achievements of this year. The STS has successfully carried a complement of seven people to work and live in space. The first passenger from private industry was orbited to pursue research and development of commercial opportunities. The extension of man's capabilities in space has been demonstrated further by the successful employment of the manned maneuvering unit (MMU).

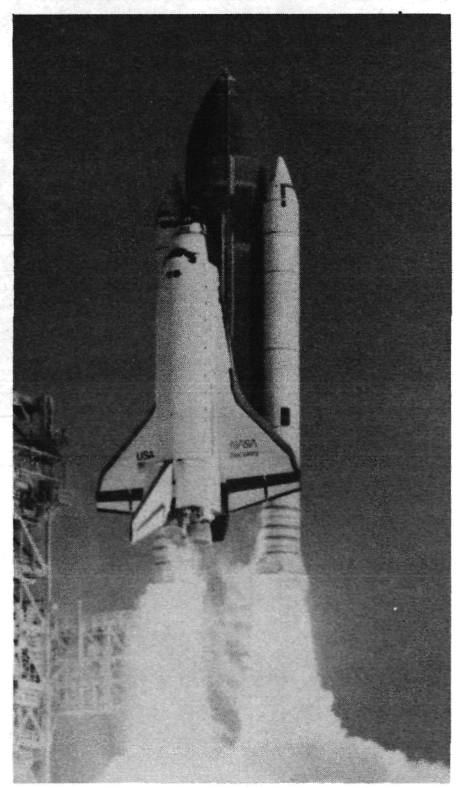
A number of commercial satellite systems were successfully deployed as well as the NASA Long-Duration Exposure Facility (LDEF) for obtaining needed low-Earth-orbit data. The retrieval, repair, and reactivation of the Solar Maximum Mission (Solar Max) spacecraft was a first but illustrative example of satellite servicing by the Space Shuttle Orbiter. Thermal insulation returned from Solar Max has contributed to the ongoing ground- and space-based investigations into the total population of manmade orbital debris. More than 1 000 impact craters were found in the insulation, a strong suggestion that there are billions of particles in low Earth orbit of sizes approaching 0.1 mm. These impact data combined with LDEF results will aid in determining the protection required for our future large space systems.

A number of successful flight experiments have been conducted, including the transfer of hydrazine in the orbital refueling system (ORS) demonstration. This experiment was not only a significant step toward providing enhanced satellite servicing capability but also a rewarding demonstration of the Johnson Space Center (JSC) skill capabilities. Another significant experiment employed the remote manipulator system (RMS) in conjunction with the payload flight test article in a series of maneuvers performed to better understand the dynamics of large coupled objects in space. Both experiments have helped to show the important potential of the Space Shuttle as a test bed for future space operations.

In addition to advancing the Space Shuttle and the capability of the STS, JSC has accepted the challenge of providing a permanent manned presence in space. First, a general continuity of development and advancement is under way at JSC in the subsystem areas associated with the Space Shuttle Orbiter, the on-orbit capability for the Space Shuttle Orbiter, and the Space Station. Second, overall Space Station system issues have been addressed by JSC independently, in support of the Space Station Concept Development Group, and within the agency-wide Space Station concept implementation activity located at JSC. Third, JSC has accepted and is initiating the management of the Space Station Level B, Systems Engineering and Integration, as well as one of the four major Level C work packages.

The systems engineering and integration of the Space Station to achieve a capable and productive permanent presence in space is a challenge within itself. There is an additional complexity, however, of time phase integration and compatibility with existing systems (particularly the STS) and future systems in addressing capability beyond the initial Space Station. For this reason as well as for the intrinsic value of foresight and perspective, JSC is examining the characteristics and requirements of future missions and associated systems. These studies include basic characterization of advanced transportation systems given the Space Station as a transportation mode, in-house characterization and design studies of aerobraking orbital transfer vehicles (AOTV's), and identification of a logical lunar exploration, development, and colonization program. The JSC conducted an in-house science and engineering activity to quantify the characteristics of both transportation and lunar surface systems and missions in an attempt to obtain more productive dialog, planning, and ideas concerning a lunar base.

Lift-off of Orbiter *Discovery* from launch pad 39-A, Kennedy Space Center.



The JSC in-house expertise in entry systems and technology is also being applied to the design and definition of a potential Aerobraking Flight Experiment which would support both the technology and the system development requirements for an AOTV. This effort is a collaborative activity with the NASA Ames Research Center, Langley Research Center, and Marshall Space Flight Center.

Space Transportation Systems Enhancements

The MMU and the manipulator foot restraint were new devices employed in both the Solar Max repair and the successful return of the nonfunctioning Palapa and Westar satellites. These tools were Space Shuttle enhancements developed through the OSF Advanced Programs activities. As the Space Shuttle fleet grows, more and more of these types of missions will be undertaken; thus, an expanding array of servicing tools and accommodations will be required.

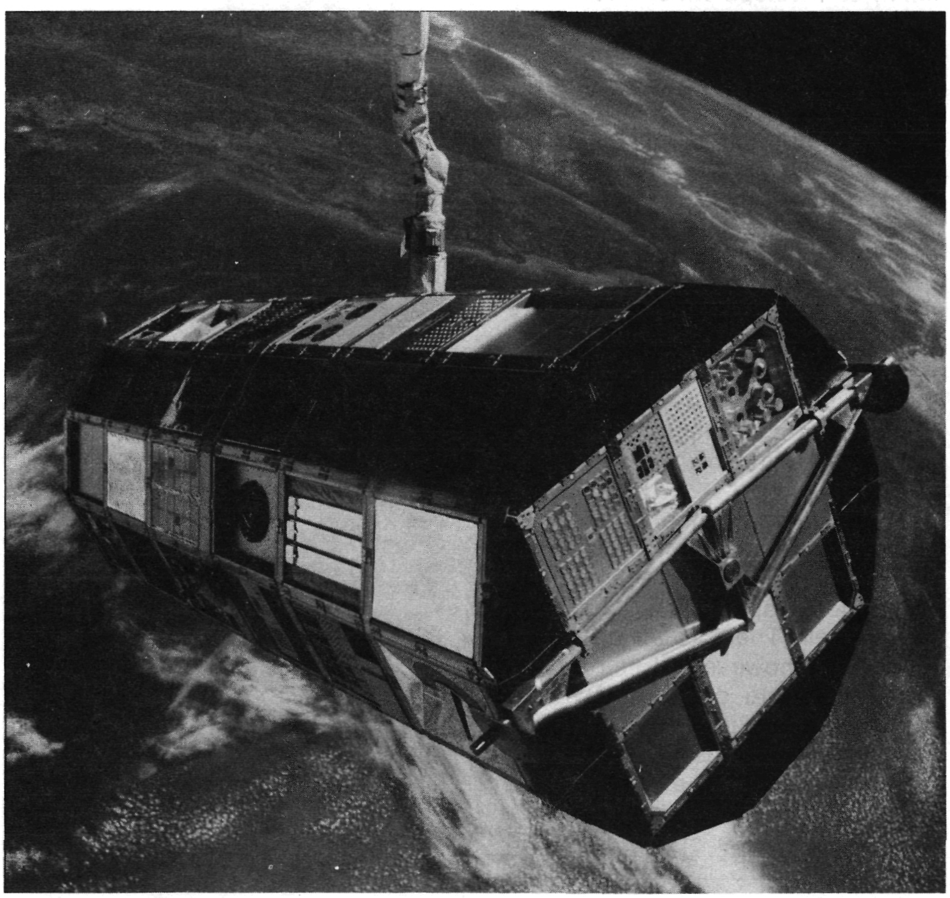
To better meet these requirements, current Satellite Services System activities include definition through study contracts and workshops, concept studies, and test-bed evaluations leading to flight hardware specifications for such proposed items as a tanker system, enhanced teleoperator functions with the RMS, a laser docking capability, and extravehicular activity (EVA) and RMS tools. The goal is to develop generic servicing equipment and standardize the servicing interfaces and thus to enable the satellite developers to consider servicing in the initial design phase. The "Satellite Services Catalog - Tools and Equipment" has been developed to define tools and equipment needed for EVA support, tool storage and payload carrier requirements, and equipment needed for satellite servicing. Also included in the catalog are descriptions of Orbiter systems used during a servicing mission.

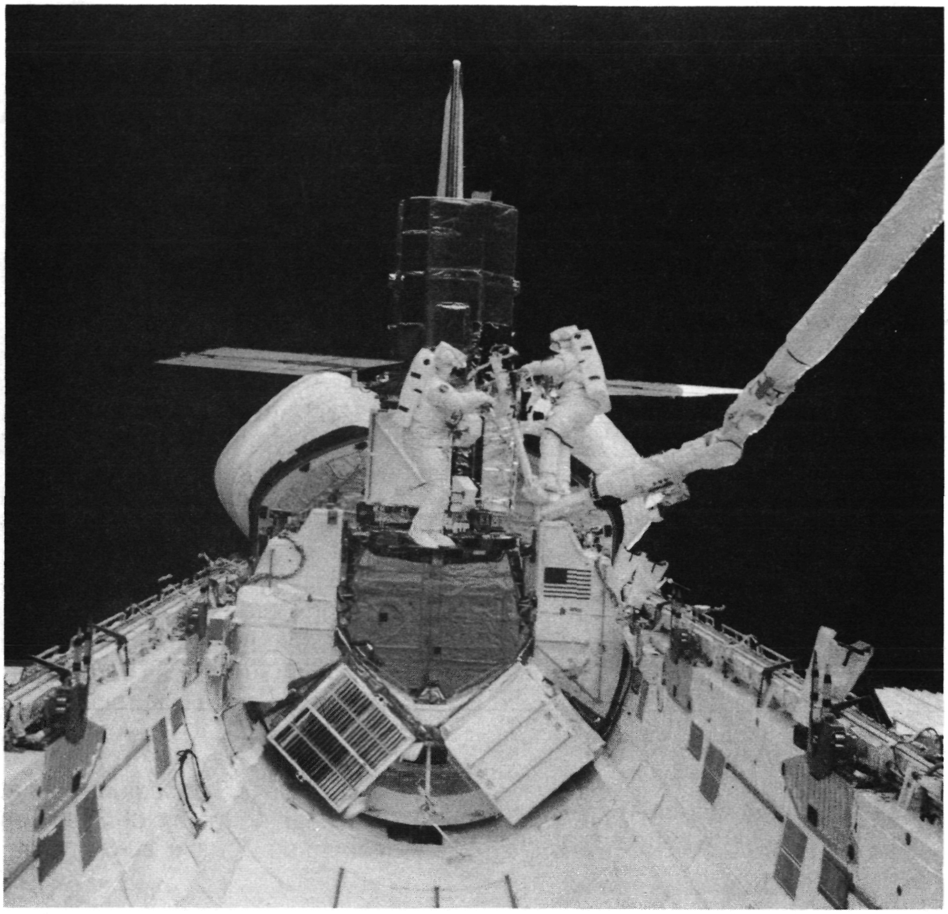
The telepresence work system (TWS) is a concept for applying telepresence and teleoperation techniques to space operations and for providing a means of demonstrating various devices, sensors, and control techniques as their technology evolves. The Orbiter will function as a flight-test facility and aid in the transition from ground testing and simulation to operational applications. The TWS should find application on the Space Station and the orbit maneuvering vehicle, in addition to becoming an operational STS system. The proposed hardware demonstration program is intended to show the feasibility and utility of giving the RMS operator force and torque feedback information. A force-torque sensor will be installed on the RMS wrist in a position to measure the loads imposed on the end effector. This demonstration system will provide immediate operational benefits to the Space Shuttle.

Also in the definition stage is a Shuttle flexible payload system interface, the aft station command and data system (ASCADS). The primary goal of the ASCADS Program activity in FY 1984 was to improve understanding of future Orbiter payloads avionics support needs. A series of requirements working group meetings supported by NASA Advanced Programs, the Department of Defense (DOD), and commercial companies produced information used to aid in the development of a payload requirements document, the "ASCADS Integrated Requirements Document" (IRD). The ASCADS IRD, which has been completed and distributed for information, integrates a combination of current and future payload requirements for the Orbiter avionics payload support system. The next steps in the ASCADS Program plan are to better develop and define the quantitative information needed on future payload requirements and to evaluate the associated implementation options. The ASCADS Program concept will have the potential of upgrading the Orbiter to provide flexibility for future growth and change and to provide a capability for minimizing the transition impact of payloads from the Orbiter to the Space Station.

Servicing of large payloads will require the capability for soft docking the Space Shuttle with a variety of objects, including orbital transfer vehicles (OTV's), the Space Station,

Long-Duration Exposure Facility being deployed in low Earth orbit on STS 41-C mission.



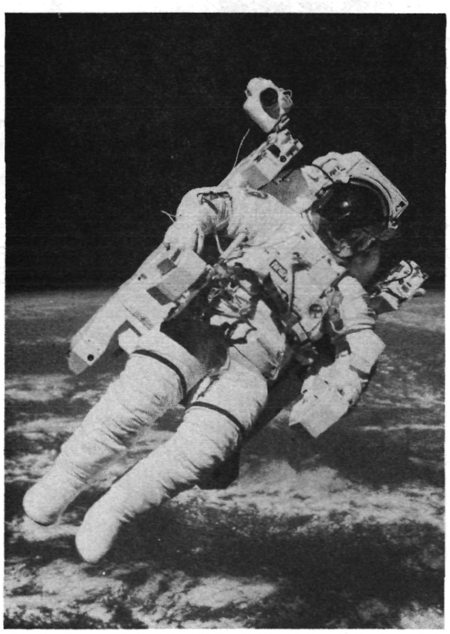


Solar Max being repaired by Mission Specialists George Nelson and James van Hoften in Orbiter *Challenger* payload bay on STS 41-C mission.

The previously mentioned ORS demonstration is one of several steps to develop the techniques and criteria to permit future use of the Orbiter as a propellant tanker for satellites. The next task is the development and demonstration of a fluid transfer system which incorporates a capillary/screen propellant management device. This equipment has been completed and is scheduled for flight test. To simplify the interface requirements for new satellites, a quick-disconnect fitting is being developed to replace the special tools required to interface existing satellite load valves. The final task under this program is the development of an operational tanker system. Preliminary concepts have been discussed, and development of this system is expected to commence in mid-1985.

Another promising innovation for providing propellants for on-orbit systems is the scavenging of unused propellant from the Space Shuttle tanks. This technique will be of particular importance with the advent of the Space Station and new orbital transfer vehicles permanently stationed in orbit. A large amount of contingency propellant remains unused on nominal Space Shuttle missions. Space Shuttle modifications and operating modes are currently

Mission Specialist Bruce McCandless II testing the manned maneuvering unit — the first untethered flight from a parent spacecraft — on STS 41-B mission, February 1984.



and free-flying spacecraft. In FY 1983, a breadboard system was established to test the concept of automated docking. A modular design approach was implemented to enable reconfiguring of the sensor for various docking vehicles. A Hero robot is programmed to various locations and tracked with the laboratory system. In another mode, a laser docking and computer controller directs the robot to a predetermined position. With these testing procedures, the accuracy of the docking sensor is established. Significant accomplishments in upgrading the performance of the laboratory system in FY 1984 included breadboarding of a scanner for a flight version of the sensor, breadboarding of compact and high-speed electronics for computations, and breadboarding and testing of improved circuits for tracking. A laser sensor has also been proposed as a part of the proximity operations vehicle (POV) demonstration experiment.

Orbital refueling system being tested by Mission Specialist David Leestma on STS 41-G mission.

being defined to allow for scavenging of monomethyl hydrazine, nitrogen tetroxide, liquid hydrogen, and liquid oxygen.

The orbital environment itself can be used to settle liquid for scavenging acquisition by means of gravity-gradient force. This force results because the gravitational and centrifugal forces of an orbiting object cancel perfectly only at the center of gravity (c.g.). The gravity-gradient force is proportional to the distance above or below the c.g. and is directed outward from the c.g. along an Earth radial. A tether is a structurally efficient means of providing long length for greater force and stability. A tethered orbital refueling facility would involve one mass attached by tether to another mass (e.g., a space station or an orbiter), with refueling to the desired space system taking place at the refueling facility. A primary candidate would be an OTV refueling facility. For feasibility, the technique must fulfill certain liquid positioning requirements. A one-half-mile-long tether from the c.g. is sufficient to settle cryogens for an OTV refueling facility.

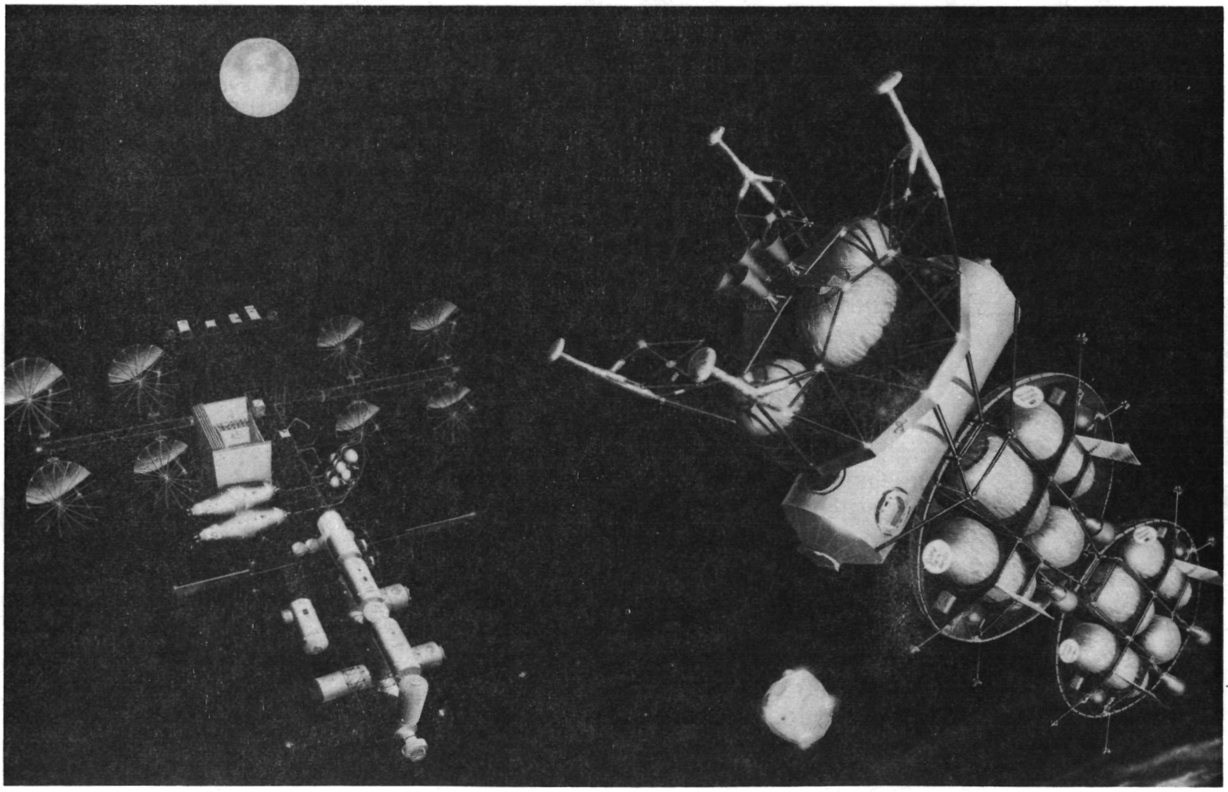
A second application of a tether involves the use of an electromagnetic tether for generation of power or as a thrust motor. The electrodynamic tether in space consists of a long insulated wire, the orbital motion of which cuts across lines of magnetic flux B to produce an induced voltage. In typical low orbits, an average voltage is about 200 V/km. Such a system should be capable of generating substantial electrical current I, at the expense of $I \times B$ drag acting on its orbital energy. If a reverse current is driven against the induced voltage, the system should act as a motor producing $I \times B$ thrust. An experiment has been designed and fabricated for flight on an early STS mission as a payload-of-opportunity to verify the fundamental operating principles. A 200-m-long wire between the Orbiter and a 10-kg deployed hollow cathode assembly will allow verification of the 30- to 50-V induced potential. A more sophisticated experiment to study the hollow cathodes and electrodynamic tether operation has been proposed in conjunction with a tethered satellite mission.

Geosynchronous and Lunar Systems Analysis

To provide the necessary guidance for a logical, rational, and integrated phased development of the Space Station, of transportation system elements, and of the supporting technology required for the year 2000 in infrastructure, several advanced planning activities were initiated in FY 1984.

1. JSC Lunar Base Report, published in April 1984
2. NASA Headquarters Post Space Station Mission Analysis Activity (ongoing)
3. Lunar Base Workshop, hosted by the Institute of Geophysics and Planetary Physics and held at the Los Alamos National Laboratory on April 23-27, 1984
4. NASA-ASEE Summer Study on Space Based Resources and Operations, held at the California Space Institute on June 17 to August 24, 1984
5. Lunar Base Symposium, held at the National Academy of Sciences Auditorium on October 29-31, 1984

Artist's conception of aerobraking orbital transfer vehicle (AOTV) departing from orbiting space station on lunar base resupply mission.



The plan for FY 1984 was to use the JSC Lunar Base Report as a primer for the Lunar Base Workshop, and the workshop itself was to serve as a planning instrument for the Lunar Base symposium. The summer study was not directed at lunar bases as such but was directed toward nonterrestrial materials, which could be asteroidal as well as lunar in origin. However, both the JSC report and the products of the workshop were valuable to the success of the summer study. The result of the Headquarters planning activity, which used data from the JSC Lunar Base Report for the definition of a lunar base subscenario, was also useful in the summer study.

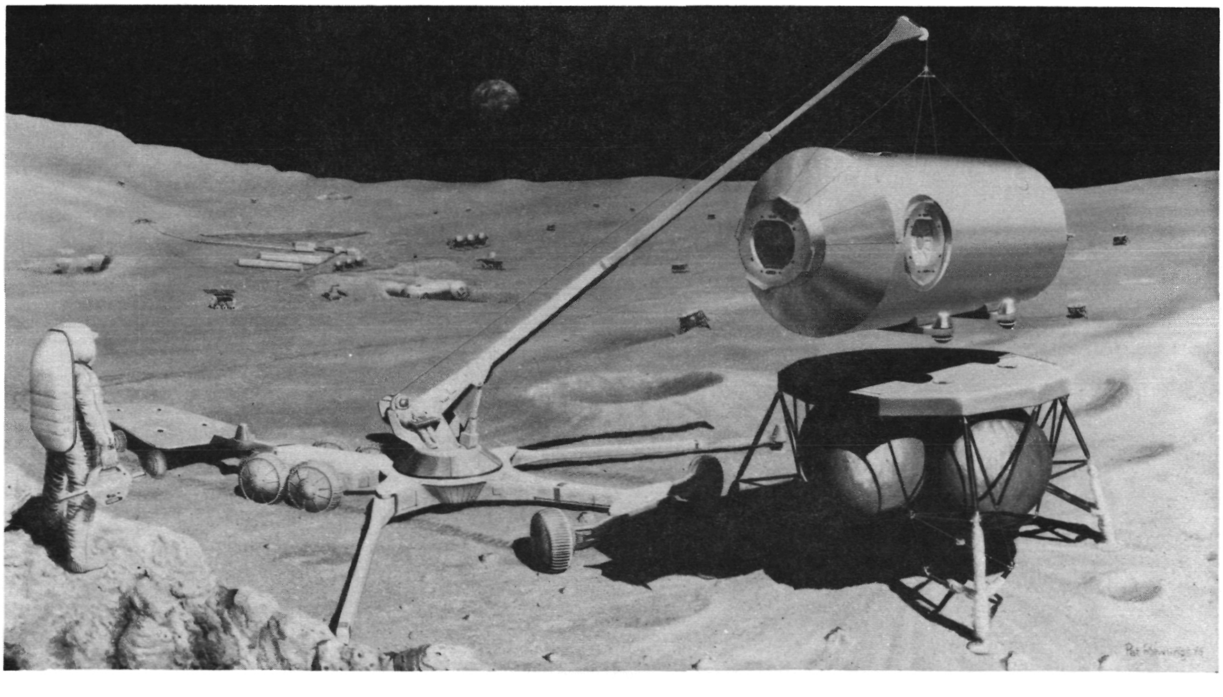
To date, these collected activities have revealed a significant and influential support for a lunar base that is self-sufficient and promotes human expansion into space—specifically, a manned Mars exploration. The JSC activity was accomplished entirely by civil service employees. The objective of the study was to construct several lunar base scenarios on the basis of Space Station and space transportation system infrastructure and technologies expected in the year 2000.

A rationale subtask identified science activities that include geophysical studies of the lunar surface and lunar core to increase our knowledge of solar system evolution as well as knowledge of the location and concentrations of lunar resources that may have substantial value as export commodities or as leverage on human expansion when used onsite to promote self-sufficiency. The environment of the Moon—low gravity, no atmosphere, stable base, and far side free of radio noise—has prompted substantial interest in cosmology and cosmic radiation experiments, in magnetospheric studies, and in measurement of the full electromagnetic spectrum (specifically for the Science and Engineering Technology Index).

A subtask on support elements addressed transportation systems, surface infrastructure, and communications systems. These support elements were evolved from expected year-2000 space infrastructure whenever possible. For example, the transfer vehicles were scaled from proposals on the agency's OTV, and the lunar surface habitats and laboratories were derivatives of Space Station modules. Surface transportation elements and major manufacturing plants were not defined beyond a requirement stage because of the lack of experience on which to build. The communications systems were based on Tracking and Data Relay Satellite (TDRS) technology and used the Earth-Moon libration points as stationary locations for relay satellites.

The study resulted in concluding that a lunar base is a rational national objective and that the impacts on the Space Station and other STS elements are significant and should be addressed soon. In FY 1985, these activities will be pursued in greater detail. The FY 1984 activity was a broad-brush feasibility assessment and search for advocacy. Because of substantial success in both categories, the rationale will be revisited and studied in greater detail in FY 1985. Two study contracts will be awarded to assess the needs for, and the opportunities provided by, a lunar base. Since there is much synergism for and since there are many related activities that could be performed by humans in geosynchronous Earth orbit (GEO), this funded activity will also include a needs and opportunities assessment for GEO. Civil service and funded support resources will be committed to the execution of options analysis and tradeoff studies. The results of the FY 1985 activities will be coordinated with an NASA-wide activity to assess the impact of lunar base operations on the Space Station.

Module transported from space station being offloaded from AOTV descent stage at lunar base.



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Space Flight
Advanced Programs

Significant Tasks

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Orbital Refueling System Development

TM: Harold E. Benson/EX
Reference OSF 1

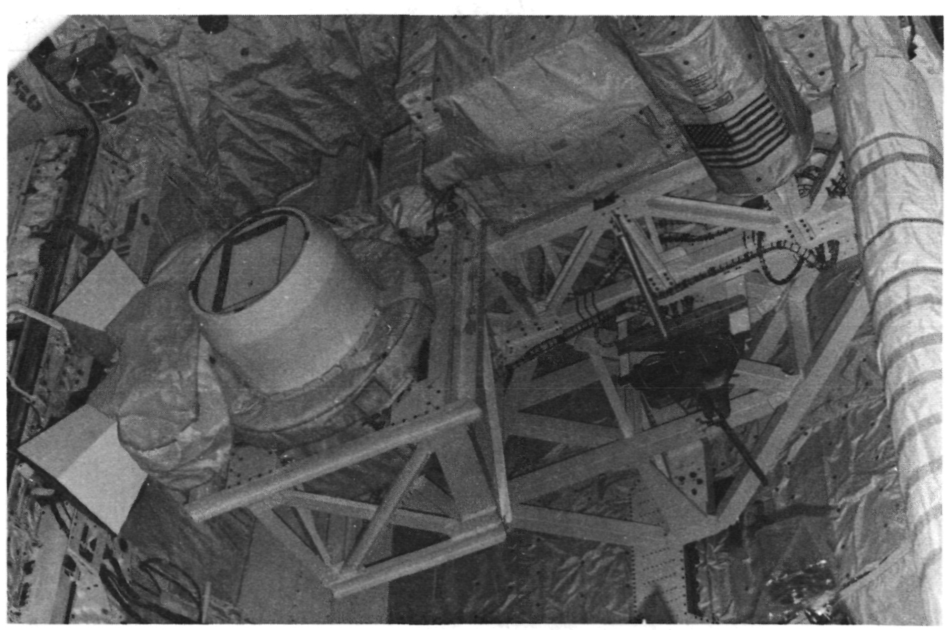
The overall objective of the orbital refueling system project is to develop the techniques and criteria to enable future use of the Space Shuttle Orbiter as a propellant tanker for satellites. Such a mission would involve sharing space with other Orbiter payloads. This activity represents a commitment on the part of NASA to develop on-orbit satellite servicing as a standard and routine operation for existing satellites and as an option in the design of future space vehicles.

Six tasks were delineated to achieve the goals. The initial task was to develop special extravehicular activity (EVA) tools to enable an astronaut, during an EVA, to interface the propellant supply with a typical satellite servicing valve which had not been designed for in-flight servicing. This task was successfully accomplished on Space Shuttle flight STS 41-B. A second task was to develop and demonstrate a fluid transfer system to transfer hydrazine in the payload bay following an EVA hookup of the previously discussed special tools. The system, using diaphragm tanks, has been completed and successfully demonstrated on mission STS 41-G. A third task is the development and demonstration of a fluid transfer system which incorporates a capillary/screen propellant management device. This equipment has been completed and is scheduled for test on mission STS 51-B.

To simplify the interface requirements for new satellites, a quick-disconnect fitting is needed to replace the special tools required to interface existing satellite load valves. A Request for Proposal was issued in September 1984 to design and fabricate this coupling, with delivery of flight-qualified hardware scheduled for March 1986. Prior to starting the quick-disconnect design and development, an industry/Government workshop was held at JSC in June 1984 to initiate a dialog with the user community with the objective of establishing requirements for the quick-disconnect design.

The final task under this program is the development of an operational tanker system. Preliminary concepts have been discussed, and development of this system, incorporating the results of prior activities, is expected to commence in mid-1985.

Hydrazine fluid transfer system flown on STS 41-G mission.



Satellite Services System

TM: Gordon Rysavy/EX
Reference OSF 2

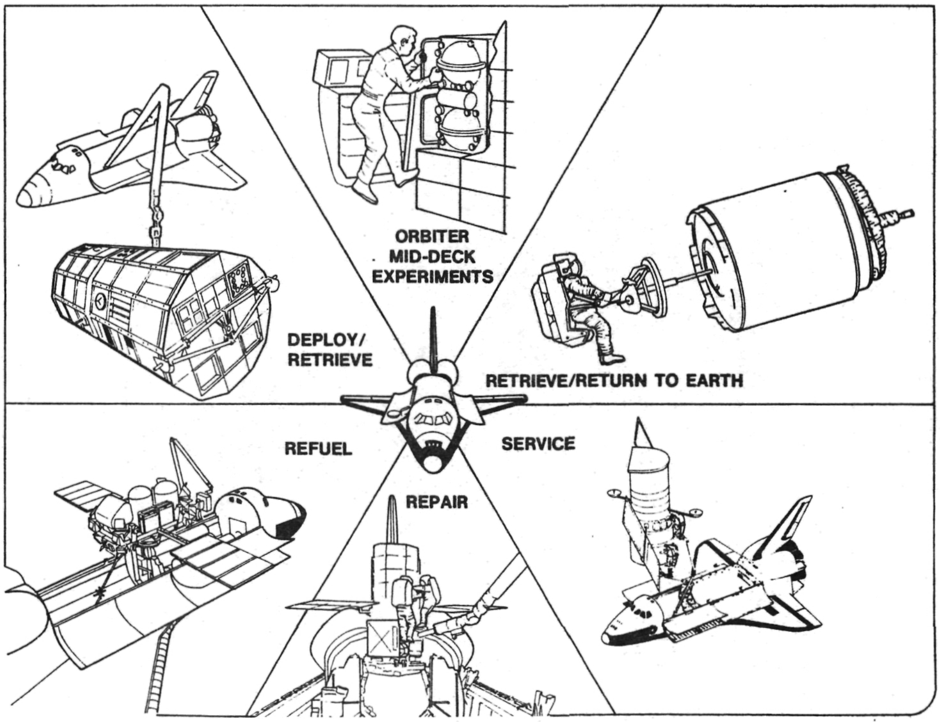
The fully operational Space Transportation System will have requirements for a wide range of satellite servicing functions, including capability for payload deployment and retrieval, payload support on sortie missions, and satellite support servicing within or adjacent to the Space Shuttle cargo bay. Potential satellite support services include (1) resupply of expendable items such as propellants or raw materials for processing, (2) checkout, maintenance, and repair, (3) reconfiguration of sensors, and (4) component exchange. Previous studies defined the requirements and provided conceptual design of various items of satellite services equipment. Some of this equipment is now available or under development, and the remainder consists of newly identified items for future development consideration.

The servicing equipment envisioned will be capable of multiple use on Space Shuttle, Space Station, and orbital maneuvering vehicles for satellites ranging from low-Earth-orbit to geosynchronous-orbiting systems. This commonality will be achieved by maintaining standard interfaces which are being developed in conjunction with the definition and development of the servicing equipment.

Activities include definition, based on customer inputs through study contracts and workshops, and concept studies. These activities are supported by test-bed evaluations leading to flight hardware specifications for such proposed items as a tanker system, enhanced teleoperator functions with the remote manipulator system (RMS), a laser docking capability, and astronaut extravehicular activity (EVA) and RMS tools.

The NASA goal is to baseline generic servicing equipment and standardize the servicing interfaces and, thus, to allow satellite developers to consider servicing in their original design phase. An initial step in the baselining of available and projected servicing tools and equipment was accomplished with the September 1983 publication of the "Satellite Services Catalog — Tools and Equipment." This catalog describes tools and equipment for EVA support, tool storage, payload carriers, and projected satellite servicing equipment. Also included in the catalog are descriptions of Orbiter systems used during a servicing mission. The effort to identify and define satellite interface design considerations with emphasis on servicing requirements for near-future satellites also resulted in the publication of the "Satellite Services Handbook — Interface Guidelines."

Space Shuttle satellite servicing capabilities.



Telepresence Work System Definition Study

TM: Lyle M. Jenkins/EX
Reference OSF 3

The use of automation and robotic techniques in space operations is becoming increasingly important as the Space Transportation System (STS) approaches operational maturity and the Space Station development proceeds. Requirements to conduct servicing operations on satellites, to perform contingency procedures, and to construct the Space Station under time-critical or hazardous circumstances all suggest the need for alternatives to extravehicular activity (EVA) by space crews.

Telepresence offers an alternative and a supplement to EVA by providing the capability to transfer a human's sensory perception to a remote site and to perform remote manipulation in which humans are responsible for generating control signals. Use of these techniques will enable the astronaut to remain within a pressurized cabin and perform, through remote-sensing devices and remotely controlled dexterous manipulators, many intricate operations that would otherwise require a space-suited EVA with its attendant training, scheduling, and safety concerns.

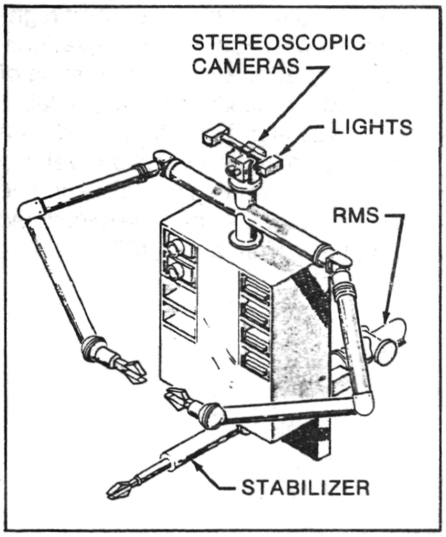
Telepresence and teleoperations incorporate a number of different technologies at various levels of maturity. The technologies relating to the sensors include television, mechanical, and ultrasonic systems for force and torque feedback; optical, ultrasonic, and other techniques for tactile feedback; and infrared and other methods of providing proximity data. Methods of mechanically duplicating the capabilities of the human hand complete with quick-change devices to permit use of a variety of tools are needed. Also, sensing, display, and control technology must interact with computer processing. With development of supervisory control, telepresence systems can use machine intelligence and optical recognition systems to relieve the human operator of repetitive or trivial tasks.

The telepresence work system (TWS) is a concept for applying telepresence and teleoperation techniques to space operations and for providing a means of demonstrating various devices, sensors, and control techniques as their technology evolves. The Orbiter will function as a flight-test facility and aid in the transition from ground testing and simulation to operational applications. The TWS should find application on the Space Station and the orbit maneuvering vehicle, in addition to becoming an operational STS subsystem.

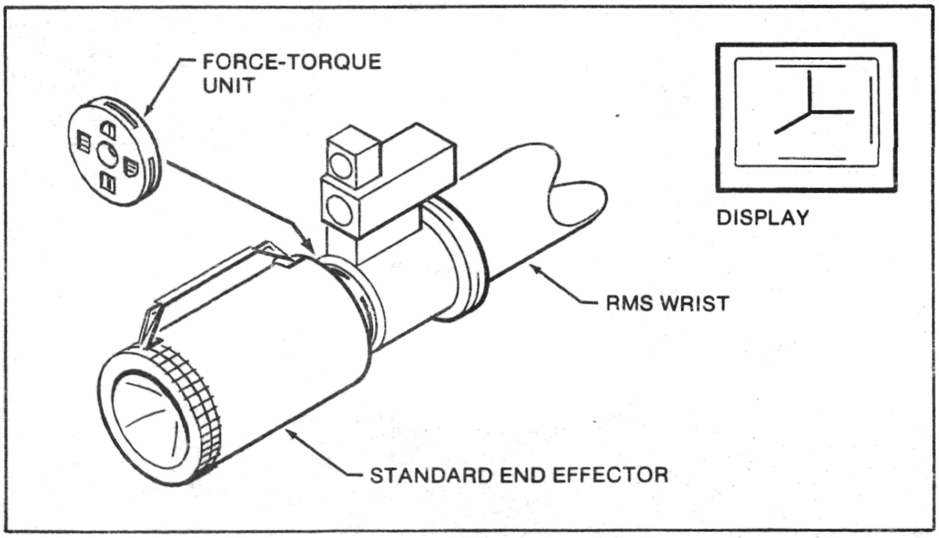
The approach taken for the development of an operational telepresence capability for the STS and the Space Station has been to initiate a development and planning study and a hardware demonstration program. The objectives of the study are to develop and evaluate TWS concepts, to define a flight-test-bed concept for demonstration of technology, and to define a program plan for the evolutionary development of a TWS. Among the guidelines is the requirement that the TWS shall interface with the Orbiter through the Shuttle remote manipulator system (RMS), which is to provide interface for attachment, power, and communications and to maneuver and position the TWS. The initial hardware demonstration program is intended to show the feasibility and utility of giving the RMS operator force and torque feedback. A force-torque sensor will be installed on the RMS wrist in a position to measure the loads imposed on the end effector. This dexterous manipulation demonstration will provide immediate operational benefits to the RMS and will support the TWS development.

Contracts have initiated TWS definition studies. These studies will last 9 months and should be completed during the third quarter of 1985. The Jet Propulsion Laboratory is developing a force-torque sensor with its associated electronics and display systems for a flight-test demonstration in 1987.

Representative telepresence work station concept.



Dexterous manipulator demonstration.



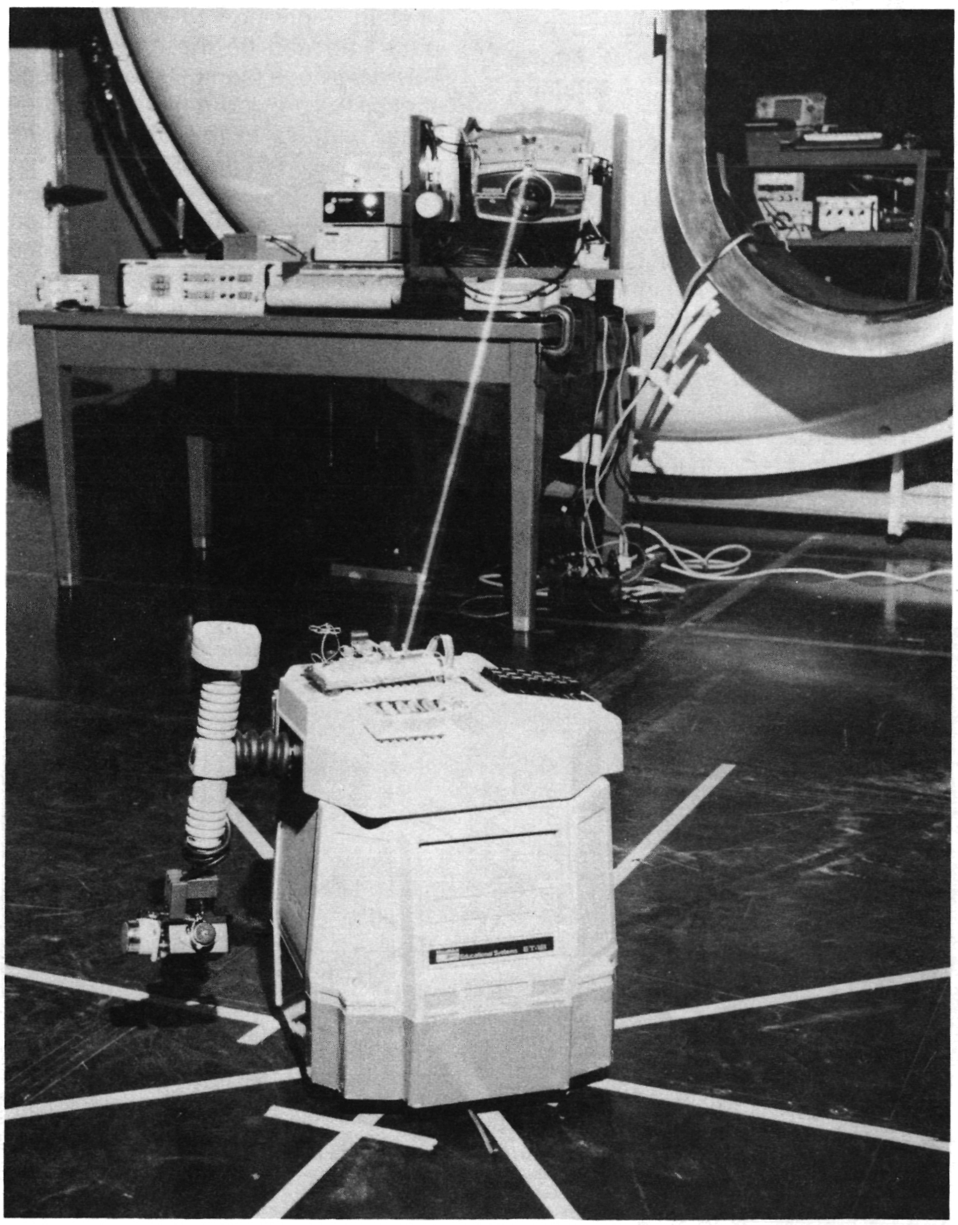
Advanced Rendezvous and Docking Sensor

TM: Harry O. Erwin/EE6
Reference OSF 4

An automatic soft-docking capability has been established as a requirement for future space operations. Provision of this capability requires development of a versatile sensor system capable of accurately measuring relative position, velocity, and attitude between many different types of spacecraft, such as orbital transfer vehicles, improved Orbiters, Space Station, free-flyers, and other vehicles involved in satellite services. Salient docking system design goals are: range, 1 to 1000 m; range-rate accuracy, 0.003 m/sec (1σ); and attitude accuracy, 10 mrad (1σ). Maximum range capability should be extendable to 50 km for rendezvous. An early need is expected for this sensor system in tracking payloads such as detached experiment carriers.

No existing sensor system can enable soft docking required in the Space Shuttle and Space Station Programs. Moreover, there is no adequate rendezvous sensor which is usable on small spacecraft. The Space Shuttle Orbiter K_u-band radar/communications system is designed to satisfy the particular, limited long-range high-data-rate requirements of the Space Shuttle and is not appropriate for other vehicles. Rather than requiring a different sensor to satisfy the unique rendezvous or docking requirements of each new spacecraft, this task will provide the design for a versatile, modular rendezvous and docking sensor which can satisfy the needs of many different spacecraft and missions. Available sensor systems in the microwave part of the spectrum have limitations in the near-range and very-low-velocity regimes. Ranging systems in the optical region using lasers can provide the needed accuracy.

Laser docking breadboard positioning robot accurately.



In fiscal year (FY) 1983, a feasibility design using heavy, nonflyable components was breadboarded to test the concept of automated docking. A modular design approach was implemented to enable reconfiguring of the sensor for various docking vehicles. Emphasis was also given to high computation speed, minimum size, and minimum weight. Testing of this feasibility model was accomplished in the JSC optical ranging test bed. As illustrated, a Hero robot is programmed to various locations, and tracking is accomplished with the laboratory system. In another mode, a laser docking and computer controller directs the robot to a predetermined position. With these testing procedures, the accuracy of the docking sensor is established. Significant accomplishments in upgrading the performance of the laboratory system in FY 1984 included (1) breadboarding of a scanner for a flight version of the sensor, (2) breadboarding of compact and high-speed electronics for computations, and (3) breadboarding and testing of improved circuits for tracking. A laser sensor has also been proposed as a part of the proximity operations vehicle (POV) demonstration experiment. The Orbiter demonstration will be completed during FY's 1986 and 1987.

STS Propellant Scavenging

TM: Gene R. Grush/EP4
Reference OSF 5

Fluid resupply will be required for future orbiting vehicles such as the Space Station, space-based propulsion stages, and serviceable satellites. Propellant scavenging from the Space Shuttle Orbiter has the potential for supplying a large percentage of these on-orbit fluid requirements. Space Shuttle systems that are candidates for scavenging include the orbital maneuvering system (OMS) and the main propulsion system (MPS). The OMS uses Earth-storable propellants monomethyl hydrazine (fuel) and nitrogen tetroxide (oxidizer). The MPS propellants are cryogenic hydrogen and cryogenic oxygen.

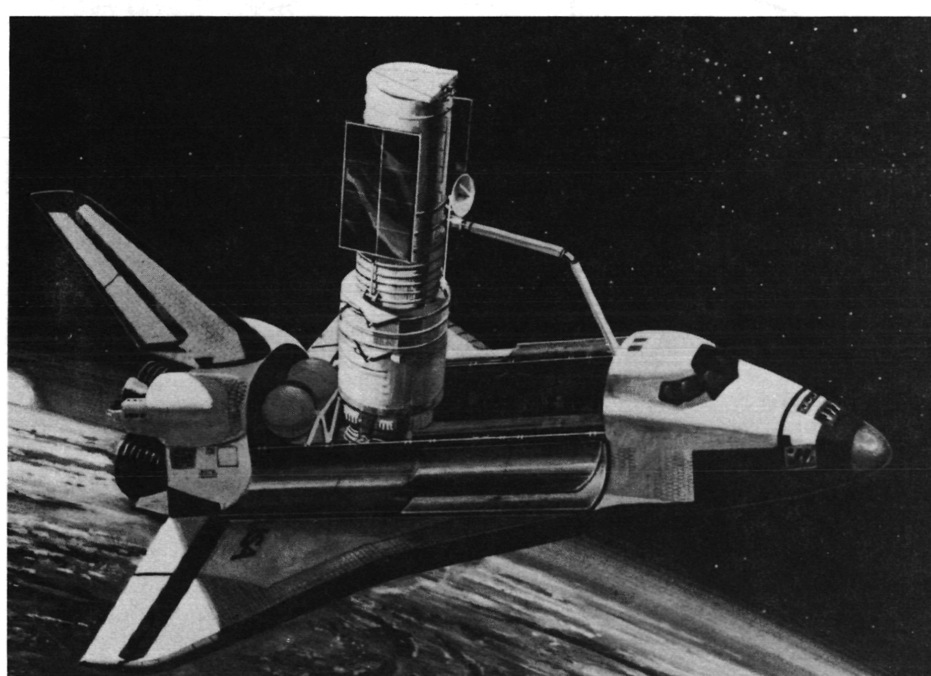
Studies have been conducted for a number of years to define the most efficient method of recovering these propellants. The cryogenic scavengeable propellant can be split into two categories. The first is the contingency propellant that remains after main engine cutoff (MECO). This propellant is referred to as excess lift capability. The other category is the propellant that is required for safe shutdown of engines. (Ingestion of gas into the main engines is possible if insufficient propellant remains at MECO.) This category of propellant is referred to as the flight propellant reserve and unusable propellant.

The proposed concept for cryogenic scavenging works in two stages. The first is to preload excess lift capability as cryogenic propellant into tanks located in the payload bay. This procedure accomplishes two goals. It minimizes the operational impact to the Space Shuttle and maximizes the excess lift capability propellant deliverable to orbit. The next stage is to transfer the flight propellant reserve and unusable propellant to the same payload bay tanks after MECO. To ensure that the external tank deorbits into either the Pacific Ocean or the Indian Ocean, the maximum allowable time for transfer of this remaining propellant is 20 min. This operation will require installation of a 2-in-diameter line between the MPS propellant lines and the payload bay tanks. The transfer will require a vehicle pitch spin of 2 deg/min to maintain the gravitational force required to settle the fluid.

The proposed Earth-storable scavenging system requires that all the propellant be preloaded into tanks in the payload bay and/or into OMS tanks. The only source for the scavenged Earth-storable propellant is the unused maneuvering propellant that may exist on that particular flight. On most flights, the OMS tanks are required to be only 70% full; therefore, the remaining 30% can be loaded for scavenging operations.

Both scavenging systems can deliver large quantities of propellant in the 1990's for use on future propulsion stages. As a result, scavenging will help reduce the cost of delivering propellant to orbit. In addition to reducing cost, the latest work has shown that preloading of the payload tanks will greatly reduce the impact on Space Shuttle operations.

Propellant scavenging system.



8.0-psi Space Suit

TM: Joseph J. Kosmo/EC5
Reference OSF 6

The current baseline in support of operational Space Shuttle extravehicular activity (EVA) requires that EVA be conducted at a suit pressure of 4.1 psia from a 14.7-psia Space Shuttle cabin. Space Transportation System crewmembers are required to prebreathe pure oxygen for 3 hr to denitrogenate before an EVA. This precaution is necessary to preclude the "bends," a painful and potentially dangerous physiological condition. The prebreathe operations require crewman-encumbering equipment, significant onboard-vehicle expendable support, and extensive crew overhead activities.

As an outgrowth of an initial study on a zero-prebreathe system, it was recognized that if higher extravehicular mobility unit (EMU) operational pressures were required for eliminating prebreathe operations, significant improvements would be required for space-suit mobility. Contracted efforts, therefore, were undertaken to investigate core technology concepts for higher operating pressure suit mobility systems.

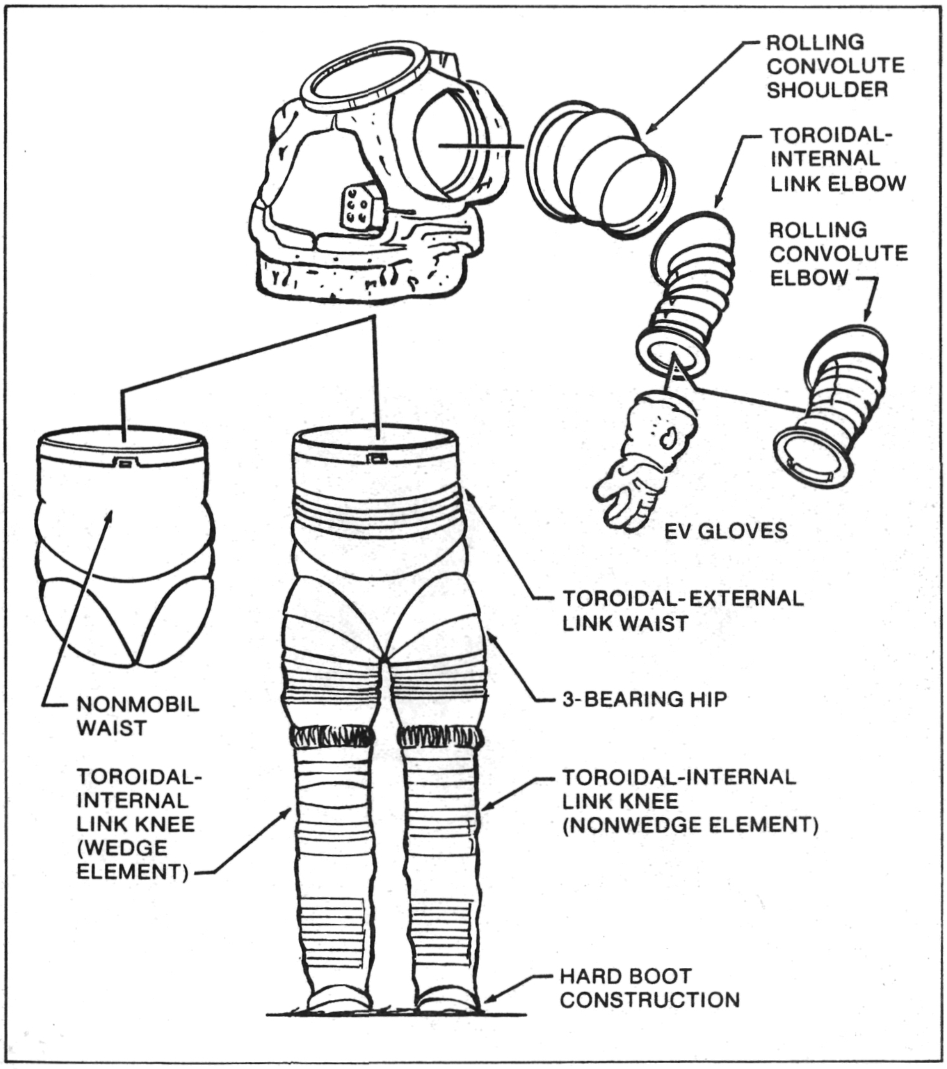
In Phase I, four different, interchangeable shoulder joint configurations; three different lower torso assemblies; two different arm/elbow joint configurations; and three different pairs of extravehicular (EV) glove configurations were designed and fabricated. Also, a current Space Shuttle space-suit hard upper torso assembly was modified for use with the zero-prebreathe suit system.

Based on results of NASA in-house testing and evaluation of the Phase I 8.0-psi technology demonstrator space suit, the following mobility joint, sizing element, and configuration upgrading activities were initiated.

1. Incorporation of miniature-roller bearings into the mobility joint linkage system to reduce torque
2. Modification of the basic laminate fabric construction layup to improve control of pressurized fabric geometry in both the rolling convolute and toroidal convolute joint elements
3. Modification of the Ortman-coupling system using flexible cable instead of rigid wire inserts for quick changeout of sizing elements
4. Development and fabrication of an internal-linkage rolling convolute elbow joint assembly
5. Development of three-bearing hip joint system to replace the original two-bearing system
6. Development of hard shell boot assemblies to increase boot service-life capabilities

In addition, NASA in-house and contractor planned test and evaluation activities for the Phase II upgraded 8.0-psi space suit will include evaluation of advantages of waist mobility features, comparative measurements of joint mobility/torque characteristics, unmanned bench-level cycle-life testing of representative mobility joint elements, and neutral-buoyancy performance evaluation testing. The Phase II hardware upgrading and retrofitting of the 8.0-psi technology demonstrator suit assembly is scheduled for completion by December 31, 1984. Testing and evaluating of the upgraded configuration is planned to start following receipt of the hardware items at JSC.

Phase II technology demonstrator 8.0-psi space suit.



Remote Manipulator System Control Technology

TM: Henry J. G. Kaupp, Jr./EH2
Reference OSF 7

Large space systems control technology will require advancements in methods of accurately modeling flexible structures, practical application of systems identification techniques, and development of closed-loop active control laws. The Space Shuttle Orbiter with its remote manipulator system (RMS) and an attached payload is a flexible structure that can be configured to represent significant aspects of large space structure operations. It is, therefore, a suitable in-space test article for investigation of on-orbit vibration damping.

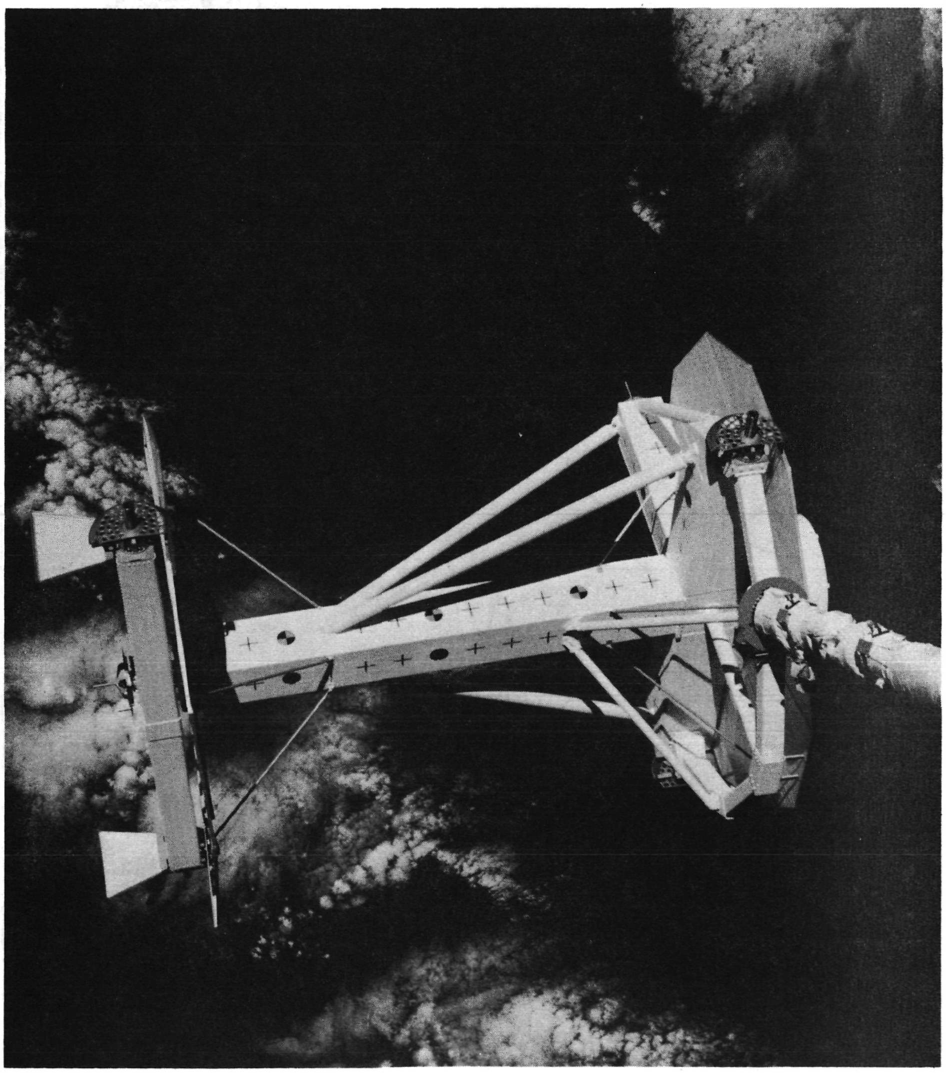
Three phases of on-orbit experiments using the RMS and instrumented payloads are being developed to investigate potential control problems associated with large space structure development, construction, and operation. The requisite sensors, control and identification algorithms, and actuators for these experiments may be provided by any or all of the RMS, payload, and general-purpose computers. The first phase of the experiments requires minimal integration with existing Space Shuttle hardware and software and will support an evaluation of current modeling techniques in addition to an assessment of the practical applicability of system identification algorithms.

Since it is not possible to implement closed-loop active control without hardware and software modifications to the Orbiter/RMS/payload system, the near-term experiments will serve primarily to augment the development of system identification algorithms and control laws for simulation of closed-loop experiments. Experiments in the second phase will incorporate the modeling and system identification experience of the first phase with flight data to simulate closed-loop active control of the RMS and payloads such as the payload flight test article (PFTA). Planning for the third phase of experiments will consider active control of the RMS and flexible payloads such as solar panels, appendages, containers, and elements of large space systems. Thus, these experiments will be closely aligned to problems associated with the construction and operation of the Space Station.

The system identification procedure used to validate the RMS model using STS-2 to STS-4 flight data required substantial engineering judgment to accommodate problems of resolution, system nonlinearity, and the interdependence of sampling rate and numerical error. Subsequently, a hybrid identification procedure, which combines Fourier transform techniques and spectral analysis, has been developed. In addition to providing estimates of system frequency, phase, amplitude, and damping, this procedure minimizes the sensitivity of the estimated parameters to noise, numerical error, and sampling rate.

A series of maneuvers using the RMS and PFTA payload was performed on STS-8. Postflight analysis of data from RMS strain gauges demonstrated that the hybrid identification procedure can potentially be integrated in an active vibration-damping algorithm. Further analysis will investigate the effect of data quantization on the accuracy of the system identification results.

Scene from STS-8 mission showing the payload flight test article suspended on the end of the remote manipulator system.



Tethered Orbital Refueling

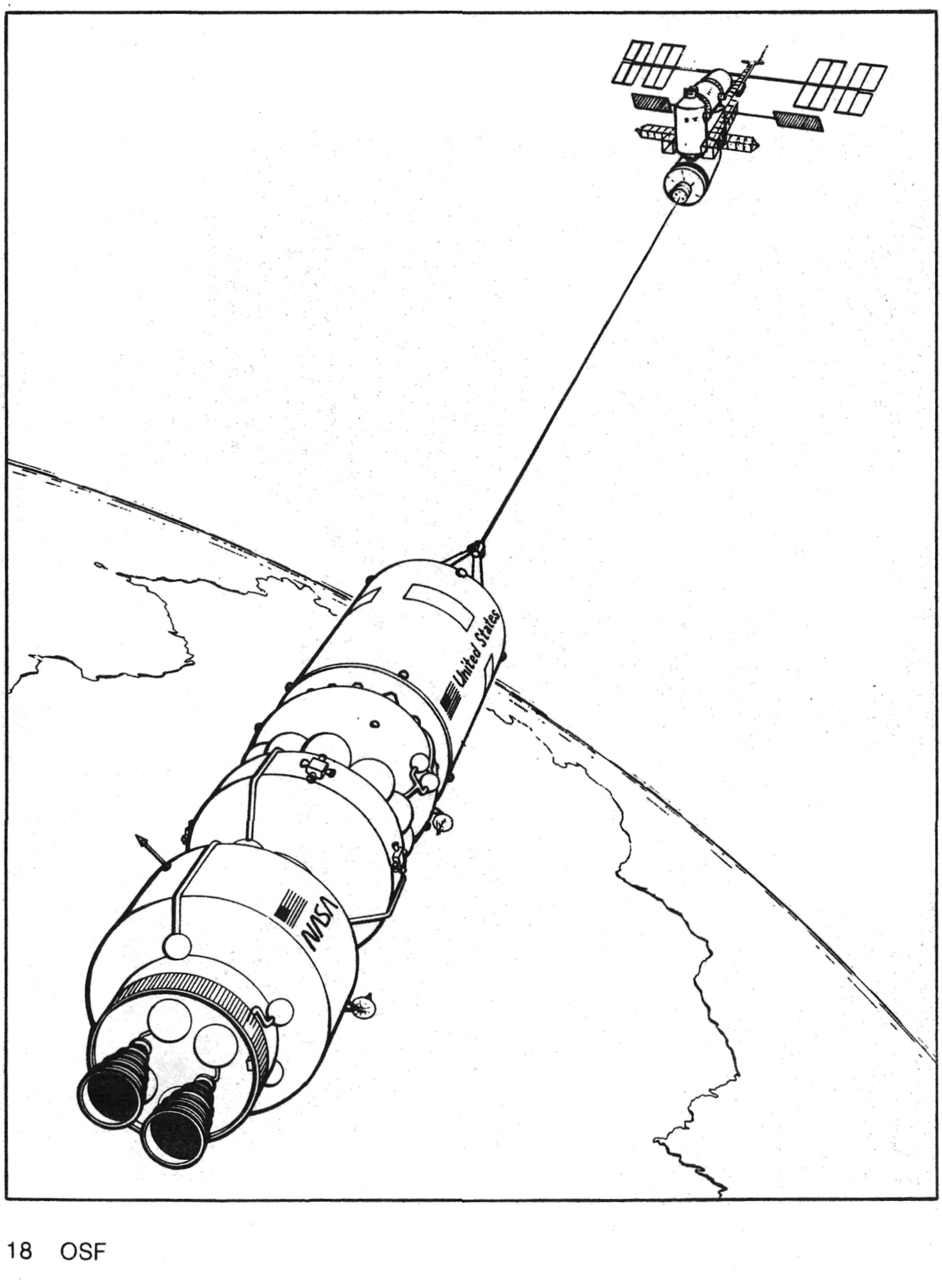
TM: Kenneth R. Kroll/EP4
Reference OSF 8

Future orbiting vehicles, such as a space station, satellites, and space-based propulsion stages, will rely on fluid resupply. To provide this function, a fluid facility that can acquire and transfer fluid will be required.

Currently, acquisition techniques such as bladders, surface tension devices, and propulsive settling are used to acquire liquid for transfer. Each of these techniques has limitations for long-term, space-based applications, especially with cryogenic fluids. Bladders, which are made of an elastic material, are frequently incompatible with oxidizers and cryogens and have leakage problems. Surface tension devices, such as screens and vanes, are ineffective in containing cryogens because of the low surface tensions, and screens are also sensitive to the vapor that may form within them from the heating of cryogens. Propulsive settling would increase supply requirements and would also create operational control complexity because of orbit changes while settling.

In addition, any nonsettling method of liquid acquisition would prevent the venting of gas. The compression of gas in the receiver tank during transfer could result in a pressure that would stop the fluid transfer.

OTV refueling facility tethered to Space Station.



The orbital environment itself can be used to settle liquid for acquisition by means of gravity-gradient force. This force results because the gravitational and centrifugal forces of an orbiting object cancel perfectly only at the center of gravity (c.g.). The gravity-gradient force is proportional to the distance above or below the c.g. and is directed outward from the c.g. along an Earth radial. At a sufficient distance from the c.g., liquid would settle and position itself toward the ends, where an outlet could be located. This configuration would simplify liquid acquisition and enable the use of conventional transfer techniques, possibly including gravity feed. The gravity-gradient force will stabilize a high length-to-width ratio pointing at the Earth, which also maximizes the force.

A tether is a structurally efficient means of providing long length for greater force and stability. A tethered orbital refueling facility would be one mass attached by tether to another mass, either a space station or an orbiter, with refueling to the desired space system taking place entirely at the refueling facility, not through the tether. A primary candidate would be an orbital transfer vehicle (OTV) refueling facility attached to the Space Station, as shown.

Currently, tethered orbital refueling appears feasible. For practicality, the technique must fulfill certain liquid positioning requirements. A one-half-mile-long tether from the c.g. is sufficient to settle cryogens for an OTV refueling facility and prevent a single disturbance from causing enough sloshing to uncover a propellant tank outlet. However, if the facility is subjected to multiple disturbances, damping is needed to prevent increased sloshing. Damping options will require further examination. Gravity feed has been examined and found to be quite slow, with inherent difficulties in reversing flow. Gravity feed is acceptable as a backup fluid transfer method, but not as a primary technique.

Electrodynamic Tethers

TM: James E. McCoy/SN3
Reference OSF 9

An electrodynamic tether deployed in space would consist of a long insulated wire, the orbital motion of which cuts across lines of magnetic flux to produce an induced voltage. In typical low orbits, an average voltage is about 200 V/km. Such a system should be capable of generating substantial electrical power. If a reverse current is driven against the induced voltage, the system should act as a motor to produce an equivalent magnitude of thrust.

A possible application could use a small system to offset the drag of a solar array system operating in low Earth orbit. Such a system might weigh as little as 100 kg, yet produce a thrust of 0.1 N at the expense of 0.8 kW of power consumed. This thrust is sufficient to keep a 100- to 200-kW solar array at nominal Space Station altitudes and thus to eliminate the need to bring more than 1000 kg of fuel to orbit annually to provide the same velocity change for orbit reboost. The system should be readily reversible from generator to motor operation by driving a reverse current using onboard power.

A reference plasma motor/generator (PMG) has been designed, capable of generating 20 kW of power into an electrical load located anywhere along the wire at the expense of 2.6 N (20 000 J/sec) drag on the wire. This system consists of 10 km of number 2 AWG aluminum wire to provide an average induced voltage of 2 kV, with 10-A hollow cathode plasma contacts at each end. In an ideal system, the conversion between mechanical and electrical energy would reach 100% efficiency. In the actual system, part of the 20 kW is lost to internal resistance of the wire, plasma, and ionosphere, and the drag force is increased by residual air drag. The 20-kW PMG system as designed is estimated to provide 18.7 kW net power to the load at total drag loss of 20.4 kJ/sec, or an overall efficiency of 92%. Similar systems using heavier wire appear capable of producing power levels in excess of 1 MW at voltages of 2 to 4 kV, with conversion efficiency between mechanical and electrical power better than 95%.

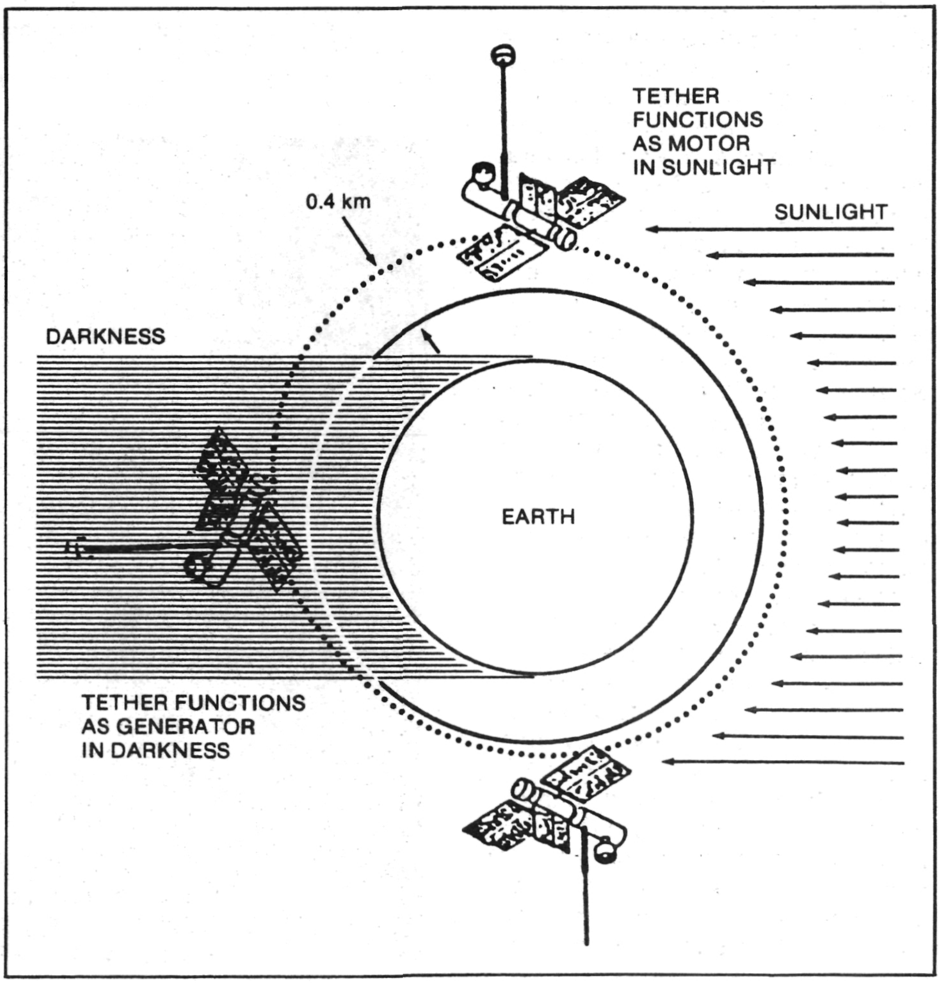
A fully reversible PMG system of this type also provides a capability to store excess solar array power output as added orbital energy during sunlight, then tap that stored energy to provide peak, emergency, or nightside power. Projected performance figures are competitive with batteries or regenerative fuel cells. Power storage capacity for any PMG mounted on a 200 000-kg vehicle (Space Station) is 250 kWh/km (of allowable altitude change).

The most promising applications would seem to involve long-duration thrust applied to spacecraft having surplus electric power available, either for the direct purpose of orbital maneuvering or for power storage by boosting the orbit temporarily. Use as a power generator appears attractive primarily as an auxiliary to other purposes, such as recovery of power previously stored, or for special situations.

A 20-kg experiment has been designed and fabricated for flight on an early STS mission as a payload-of-opportunity to verify the fundamental operating principles of these hypothetical systems. A 200-m-long wire between the Orbiter and a 10-kg deployed hollow cathode assembly will allow verification of the 30- to 50-V induced potential and its variation with current flow through the wire and back via the Earth's ionosphere.

Both passive collection and hollow cathode current coupling to the ionosphere will be tested at both ends of the wire. A more sophisticated experiment to study the hollow cathodes and electrodynamic tether operation has been proposed for the tethered satellite system flights in 1987 and 1990.

Electrodynamic tether power storage.



Orbital Debris

TM: Donald J. Kessler/SN3
Reference OSF 10

Significant advances have been made in measuring the orbital debris environment of particles smaller than the 5000 objects normally cataloged by the North American Air Defense Command (NORAD). The data used were obtained from ground-based radar, ground-based optical telescopes, Orbiter window surfaces, and returned Solar Max thermal insulation surfaces. Analysis of each of these sources revealed a significantly increasing population with decreasing size.

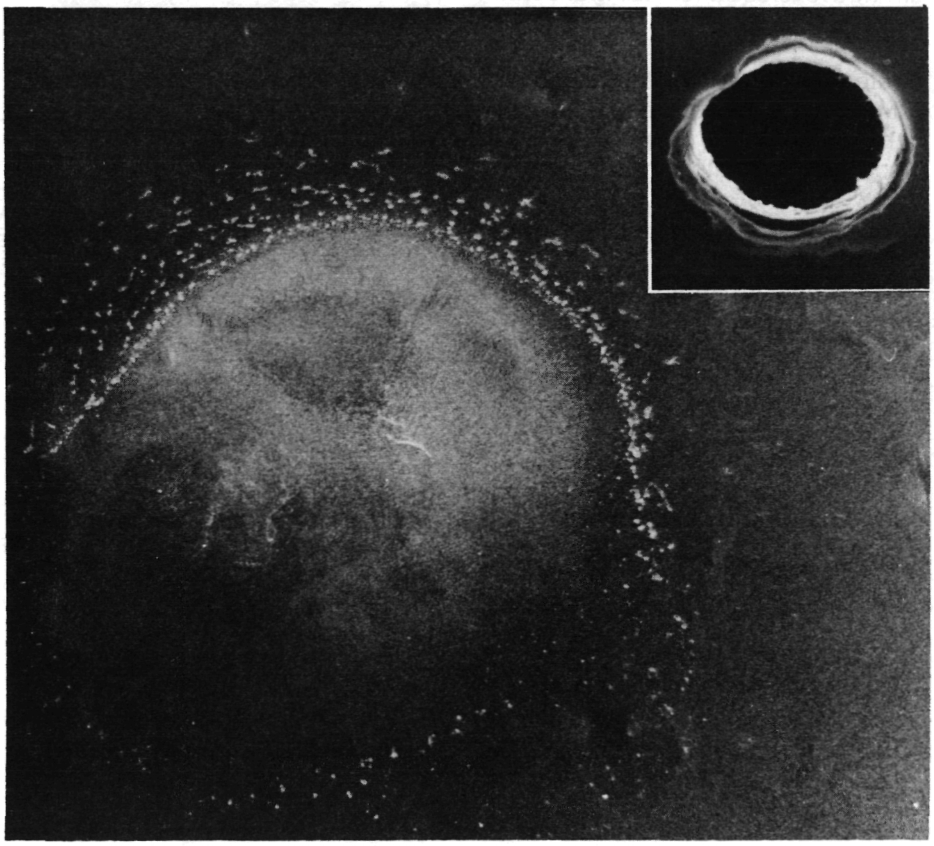
A contract was let to examine data taken by NORAD radar, which routinely detects objects as small as 8 cm in diameter. Preliminary results include at least 1000 uncataloged objects in the size interval 8 to 20 cm.

Lincoln Laboratory was contracted to use their Experimental Test Site, consisting of two 31-in. telescopes, to search for centimeter-sized debris in low Earth orbit. The telescopes tracked identical overhead star fields for about an hour using low-light-level TV cameras and video tape. Centimeter-sized objects were seen as 16th-magnitude objects moving at several degrees per second. Two telescopes were needed to obtain the altitude of the object, using parallax. This technique permitted discrimination between space debris and meteors, which are always found at altitudes below 120 km. The detection of eight times the orbiting objects predicted using the cataloged population indicates that the total population of objects larger than 1 cm in low Earth orbit is approximately 40 000. Additional tests of this type are planned to determine probable sources.

Three days after the launch of STS-7, the crew reported a pit, about 4 mm in diameter, on the external surface of a window (later replaced). This pit and several other smaller pits were removed intact from the window and subjected to scanning electron microscope (SEM) examination. Energy dispersive x-ray analysis (EDS) was used to determine the composition of partly fused material found in the bottom of the pit. Only titanium and a small amount of aluminum were found. Crater morphology places the diameter of the impacting particle at 0.2 mm, and the velocity, between 3 and 6 km/sec. From these data, it is concluded that the particle was manmade and in Earth orbit. The source of the titanium is unknown, although it may be related to material found in impact craters on surfaces returned from Solar Max.

Approximately 0.5 m^2 of thermal insulation surface from the returned Solar Max is being examined at JSC. Solar Max was in orbit for about 50 months at an altitude just above 500 km. The thermal insulation consisted of 17 outer layers of aluminized Kapton, each separated by a Dacron net. This type of surface has capture properties similar to those on an LDEF experiment and offers an excellent opportunity to obtain chemistry of impacting particles. About 160 impacting particles penetrated the outer layer and deposited ejecta on the following layers. More than 1000 impacting particles did not penetrate the first layer—more than expected from meteoroid impacts alone. The EDS analyses show evidence that most of the smaller craters were produced by particles with sufficient velocity to produce melting. Analysis also shows that a large number of these pits contain titanium, zinc, potassium, silicon, and chlorine, which, except for chlorine, corresponds to the chemistry of thermal paints used by NASA for space applications. Other pits contained only aluminum, but whether the aluminum came from the impacting particle or from the thermal insulation is unclear. One definite meteoroid impact has been identified. These preliminary results suggest that there are billions of 0.1-mm debris particles in Earth orbit. More SEM studies are planned to determine the ratio of debris to meteoroid impacts, and to identify the source of debris.

Enlarged SEM photographs of orbital impact damage to Solar Max thermal insulation. The impacting particle penetrated the outer (Kapton) insulation layer, creating a 0.3-mm-diameter hole (inset, original magnification 47×), and spread ejecta over 5 mm of an inner layer (foreground, original magnification 12×).



Aeronautics and Space Technology

Summary

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Office of Aeronautics and Space Technology

Summary

During fiscal year (FY) 1984, the Lyndon B. Johnson Space Center (JSC) pursued a variety of activities under the sponsorship of the Office of Aeronautics and Space Technology (OAST) Space Research and Technology (R&T) Base, Space Station Augmentation, and Aeronautics Programs. Most of the activities were continuations of FY 1983 Space R&T Base projects directed at developing technological readiness for the Space Station. These activity areas include systems automation, human factors and man/machine interfaces, space mechanisms, communications and tracking, crew and life support, energy generation and storage, and thermal management. The work in the last four areas was supplemented with Space Station Augmentation Program funding.

Another important support area is Advanced Space Transportation Systems R&T. Studies included are control and guidance technology, in-house testing of advanced propulsion components, and continuing support to the Orbiter Experiments (OEX) Program, for which JSC provides the overall integration management and program planning.

Generic technology is being developed for optical processing, advanced radar sensors, fluid and thermal physics, and materials technology. The JSC also participates in the Aeronautics Program, which sponsors work in information systems and aircraft materials and substructures development and testing.

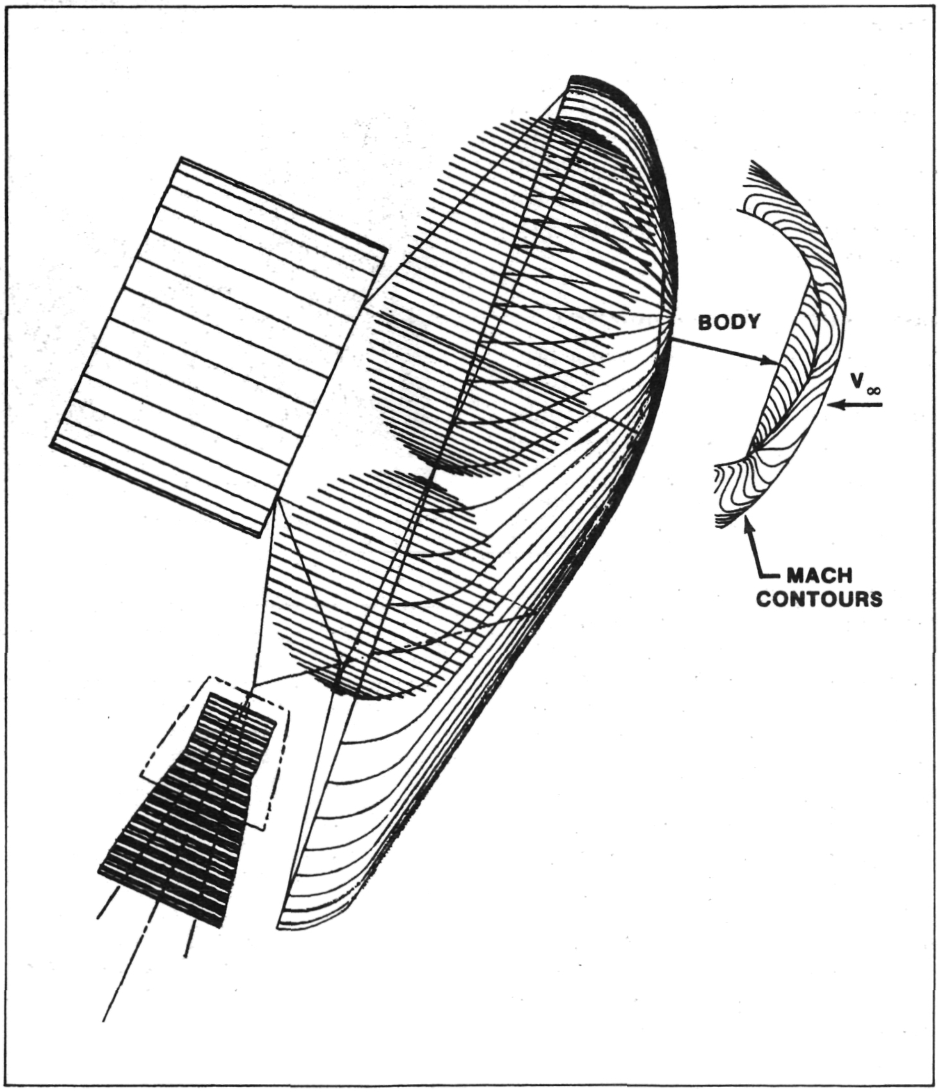
Fluid and Thermal Physics R&T

In FY 1984, JSC initiated a study of aerothermodynamic flowfield technology. Using the experience and expertise gained from the Space Shuttle Program, analytical and experimental work will be conducted to extend and update flowfield codes needed to establish realistic heating environments and thermal protection system design for future aerobraking orbital transfer vehicles (AOTV's). A typical flight experiment configuration is illustrated.

Material and Structures R&T

Two small Material and Structures R&T projects are included. The first involves investigating the effects of hypervelocity impacts on composite materials. This project examines the very real problem of micrometeorite and space debris impacts on space

A computer-aided-design-generated AOTV flight experiment configuration diagram used for *aerothermodynamic flowfield calculations.*



vehicles such as the Space Station. The second project, more futuristic, consists of research in chemical and physical processing for the extraction of usable materials from lunar rocks and soils. These projects are reported in the Solar System Exploration section of this document.

Computer Science and Electronics R&T

Programmable mask technology is being explored for applications such as pattern recognition for robotic vision, voice recognition, and communications and radar signal processing. Research in multifunction synthetic aperture radar technology has been continuing with the objective of demonstrating at least a twofold increase in capability over single-frequency systems and extremely high resolution for a wide range of mapping missions. System automation technology is also being developed under Computer Science and Electronics R&T. Generic automation techniques will be demonstrated using both mathematical model simulations and actual hardware components of the air revitalization group associated with the environmental control and life support system. (See "Platform Systems R&T.")

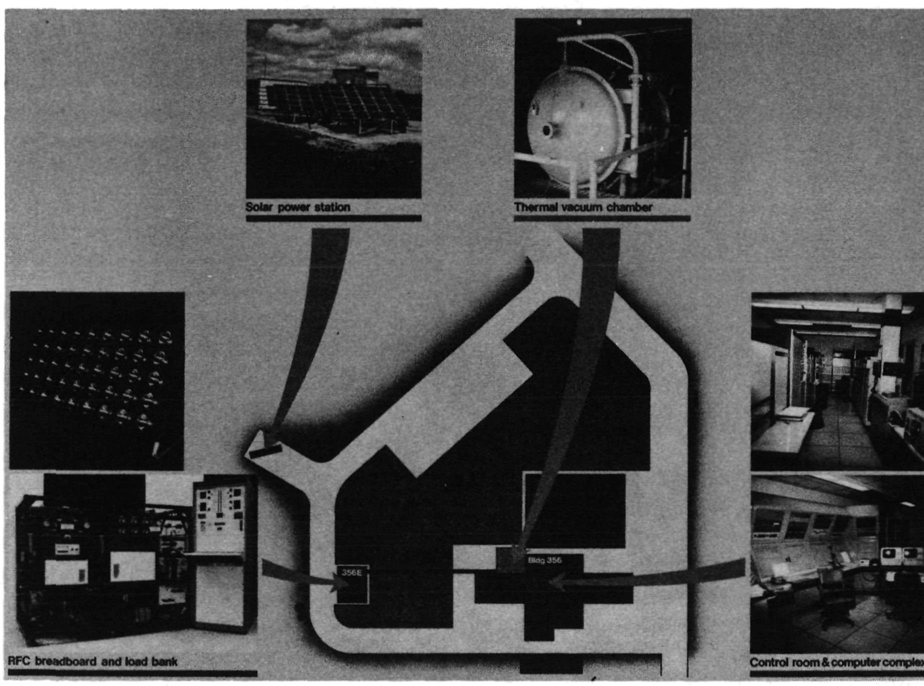
Space Energy Conversion R&T

The JSC is pursuing two major programs in Space Energy Conversion R&T: (1) regenerative fuel cell technology and (2) thermal management of large spacecraft systems. The regenerative fuel cell activity, being conducted in cooperation with the NASA Lewis Research Center, is investigating both acidic and alkaline electrochemical technologies to determine the optimum configuration for extended low-Earth-orbit mission applications. Illustrated is the JSC test facility in which a solid polymer electrolyte (acidic) breadboard system is being tested. In thermal management activity, the needed technology for efficient thermal acquisition, transport, and rejection for large power systems is being developed. A key element in this development is the two-phase heat pipe, a cross section of which is illustrated. A small experiment utilizing this heat pipe in a radiator configuration was flown on the eighth Space Transportation System mission (STS-8).

Controls and Human Factors R&T

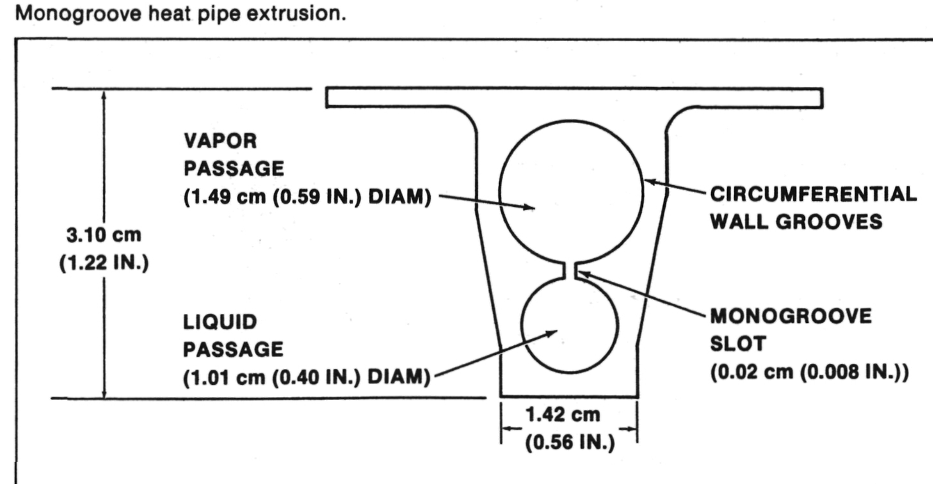
Several tasks are being undertaken in Controls and Human Factors R&T. Controls and guidance concepts and techniques are being developed to enhance the utility of current and future space transportation systems. Methods are being developed to expand the Space Shuttle Orbiter's on-orbit control envelope to accommodate large payloads and structures appended to the Orbiter as flight experiments or, in the case of the Space Station, deployment and assembly operations. Also being developed are generic techniques which will be useful for Space Station control when the configuration is undergoing large mass and inertia variations from assembly, docking, mobile crane motions, etc.

Human factors research is focused on the development of technologies that will lead to increased efficiency of man/machine interactions and, hence, crew productivity in space. A substantial part of this effort is in developing methods and techniques to provide the data necessary to ensure proper design integration of the human with the machine systems. Techniques for modeling human



Regenerative fuel cell test facility.

Monogroove heat pipe extrusion.



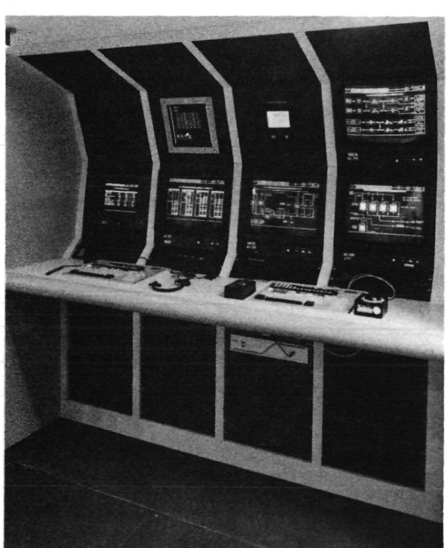
strength, movement, and size are being developed for eventual inclusion in automated crew station design programs. A second area of research is concerned with the multiple aspects of communication through crew station display and control consoles. Various factors such as graphics formats, color codings, character density, and interactive display techniques are being evaluated. This evaluation activity is supported by the illustrated crew station mockup. The mockup was developed with in-house resources in support of the Space Station Program. A third part of this effort is associated with human factors aspects of extravehicular activity (EVA). It includes biomechanical analysis of EVA's and EVA-related hardware technology such as an improved space-suit glove and a helmet-mounted "heads-up" display system.

Space Data and Communications R&T

The principal work in Space Data and Communications R&T is the development of technologies required for the Space Station communications and tracking system. The multiple system requirements are illustrated. Included are antenna technology, optical and radiofrequency (RF) communications, optical ranging and tracking, and advanced signal design techniques to ensure optimum system performance. A second project is the development and evaluation of a magnetic bubble memory system which can be used as a mass data storage system or, in an alternate configuration, as a data acquisition and recorder system for small experiment payloads. Work in the testing and evaluation of the Department of Defense (DOD) Ada computer language also is being supported. As a result of NASA's common interests with DOD in reducing the costs of software for embedded computer systems, JSC has begun a project to test and evaluate the DOD Ada language and tools for their suitability for use in future NASA space-flight systems as a standard. Contingent on the results of these evaluations, JSC will develop NASA standards and policies on the use of Ada as well as plans and guidelines for the transition from the High Order Assembly Language for Shuttle flight computer (HAL/S) standard to Ada.

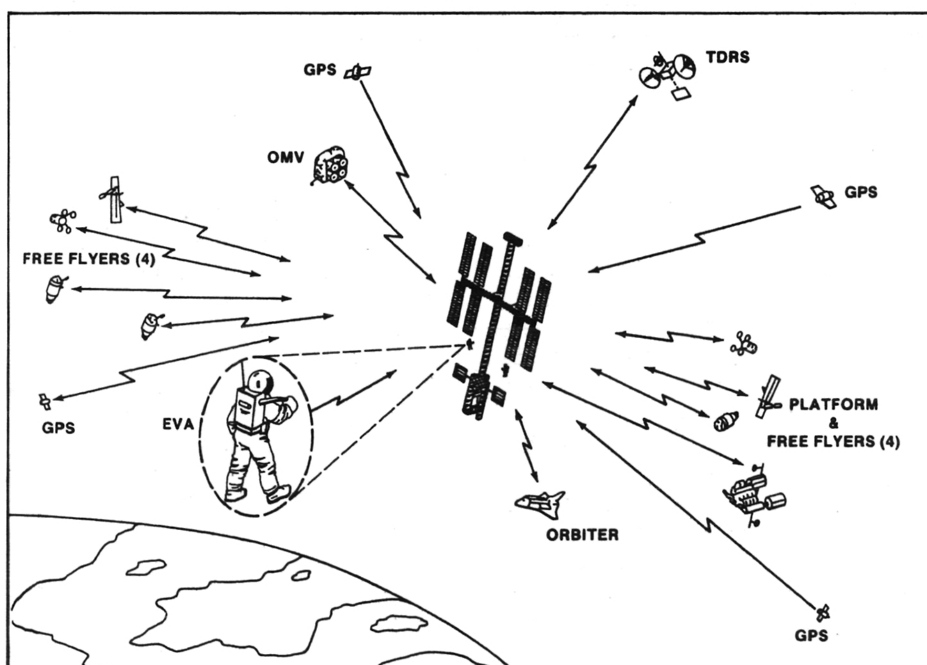
Transportation Systems R&T

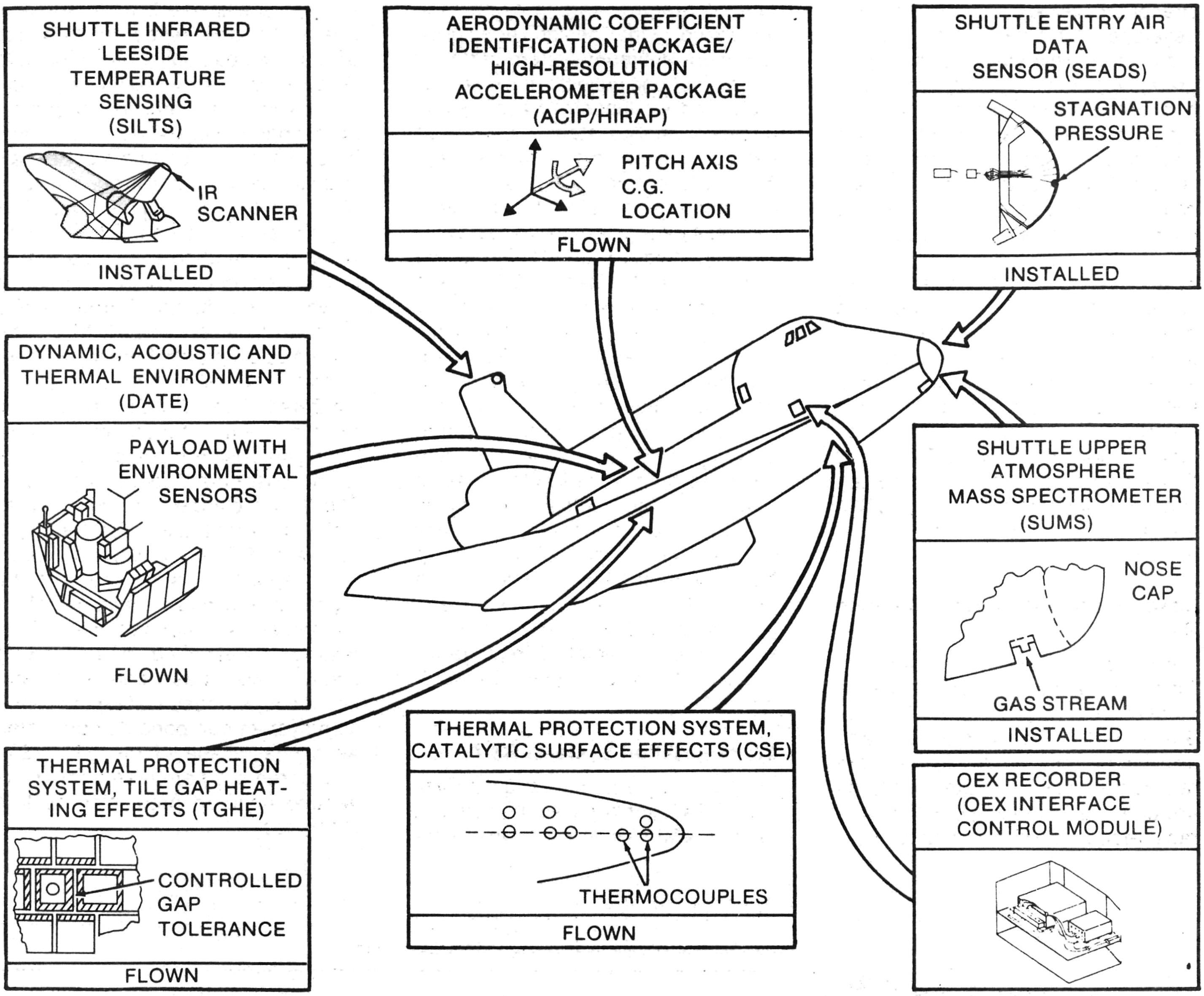
The OEX Program, JSC's major activity in STS R&T, supports technologists at various NASA centers who are developing Space Shuttle flight experiments relevant to this research. Although JSC's principal function is to provide OAST support in overall management and experiment/vehicle integration, center personnel also act as Principal Investigators on certain flight experiments. The JSC has also been responsible for the development of OEX flight support systems. The accompanying illustration shows several of the experiments which have been flown and the Shuttle Infrared Leeside Temperature Sensing (SILTS), the Shuttle Upper Atmosphere Mass Spectrometer (SUMS), and the Shuttle Entry Air Data Sensor (SEADS), which have been installed on the Orbiter *Columbia* during the vehicle modification activity at the spacecraft contractor facility. Flights are planned to begin in May 1985. In preparation for the flight program, JSC has recently completed an integrated systems test of the electrical and data subsystems of the experiment and support systems. This testing is described in a following section. Also described in a later section is in-house testing of propulsion system components conducted as a final phase of the STS-R&T-sponsored program researching advanced onboard propulsion system technology.



Space Station command console mockup incorporating color-interactive displays.

Space Station communications and tracking links.





Orbiter Experiments Program.

Platform Systems R&T

Platform Systems R&T is composed of a variety of individual technology development tasks which are aimed at meeting the requirements of the Space Station Program. A major activity is the development of subsystem technology for an advanced regenerative life support system. Research is being conducted on processes, subsystems, and ancillary instrumentation required for air revitalization and water recovery. Breadboards of advanced subsystems developed under this program are evaluated in JSC's Regenerative Life Support Systems Test Laboratory.

Platform Systems R&T also is supporting the Space Station with efforts in berthing and docking systems technology, techniques for zero-g quantity gauging of cryogenic fluids (in support of the Lewis Research Center's Cryogenic Fluid Management Facility), and data management system architectures. Operational aspects of the Space Station are also being addressed in tasks intended to develop methodologies for cost-effective operations and increased crew productivity. Areas of concern are allocation of ground as opposed to onboard functions, level of onboard automation for system checkout and activation, and other factors that can represent trade-offs between developmental and operational costs.

Spacecraft Systems R&T

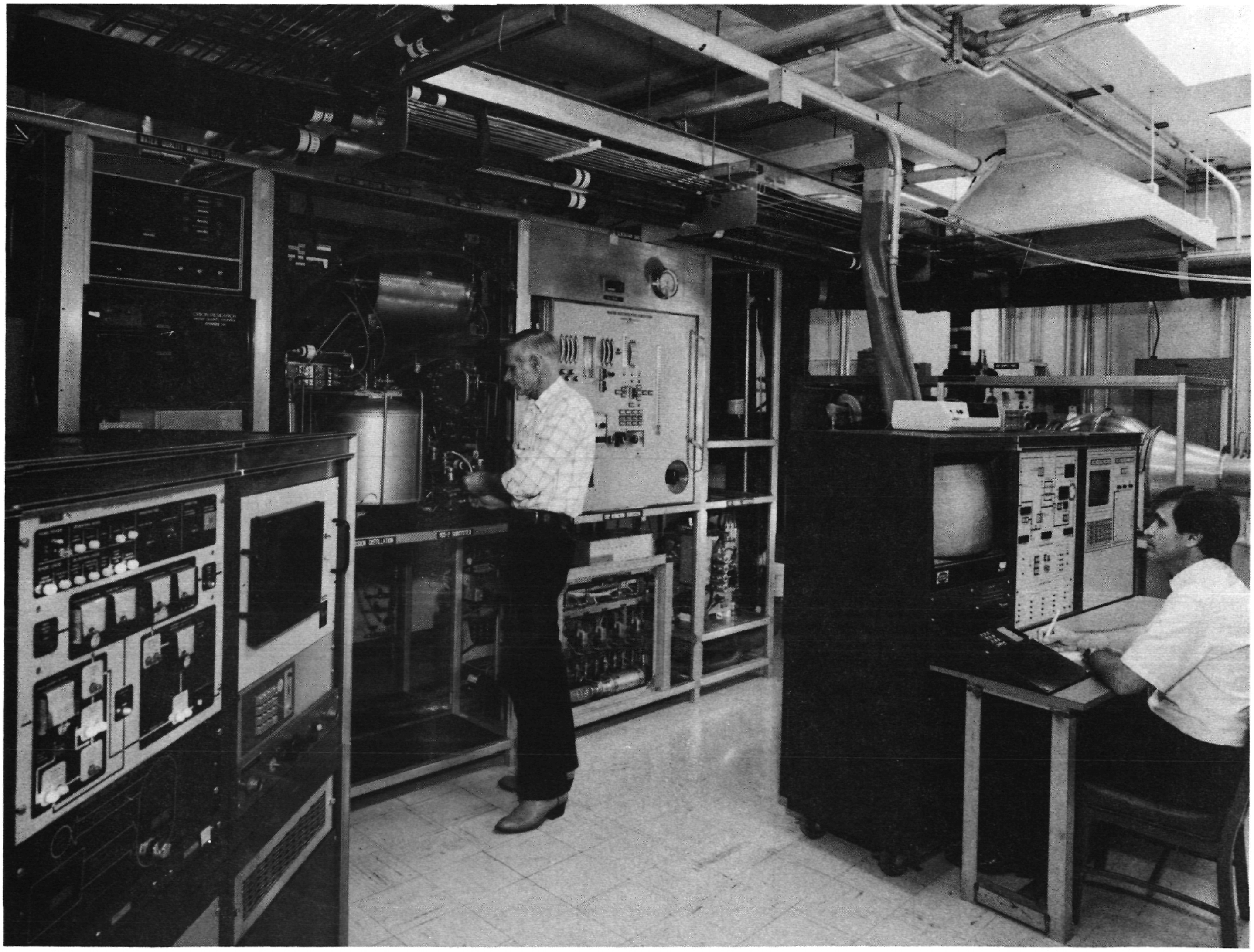
Two Space Shuttle flight experiments are supported by Spacecraft Systems R&T. The first deals with the effects of atomic oxygen on a number of spacecraft materials and coatings. The second is a followup to the STS-8 heat pipe radiator experiment mentioned earlier. This program supports the development of a full-scale (50 ft long) radiator element to be flown on a future Space Shuttle mission.

Aeronautical Programs

The JSC performs a continuing activity in support of aircraft firesafety. In previous years, candidate aircraft materials were developed and tested for fire resistance, low-smoke characteristics, and toxicity evaluation. Materials developed through this program have numerous uses in wall and floor panels, seats, galley structures, and the overall cabin area. The current program involves the fabrication of selected substructures which are undergoing evaluation in commercial aircraft.

The Aeronautical Program also supports activity in information system technology having the goal of development and demonstration of a system architecture and associated design and evaluation methodologies which will effectively serve the need for advanced information processing across a broad spectrum of future NASA missions. The program also supports the HAL/S Language Definition and Coordination Group established to provide language control for the standard compiler, tools, and documentation.

Regenerative Life Support Systems Test Laboratory.



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Aeronautics and Space Technology

Significant Tasks

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Advanced Manned Vehicle Onboard Propulsion Technology

TM: William C. Boyd/EP4
Reference OAST 1

As space operations progress toward routine aircraft-type operations, there will be an increasing need for propulsion system propellant combinations which allow rapid and cost-efficient vehicle reservicing, and which are less hazardous than conventional propellants. The current propellant combination used in the Space Shuttle on-orbit propulsion systems and in many of the bipropellant satellite propulsion systems is nitrogen tetroxide (NTO) and monomethylhydrazine (MMH). These propellants are hypergolic, toxic, carcinogenic, corrosive, and expensive. Full protective clothing must be used when handling these propellants. The system must be decontaminated before components can be replaced, and other ongoing vehicle servicing activities are normally terminated or severely impacted when these fluids are being transferred. For propulsion systems of future reusable space transportation systems, such as a second-generation Space Shuttle and on-orbit maneuvering vehicles, a noncorrosive, nontoxic, and less costly propellant combination may be desirable. However, the technology data base required for development of systems using alternative space-storable propellants is not sufficient to justify phasing out hypergolic propellants.

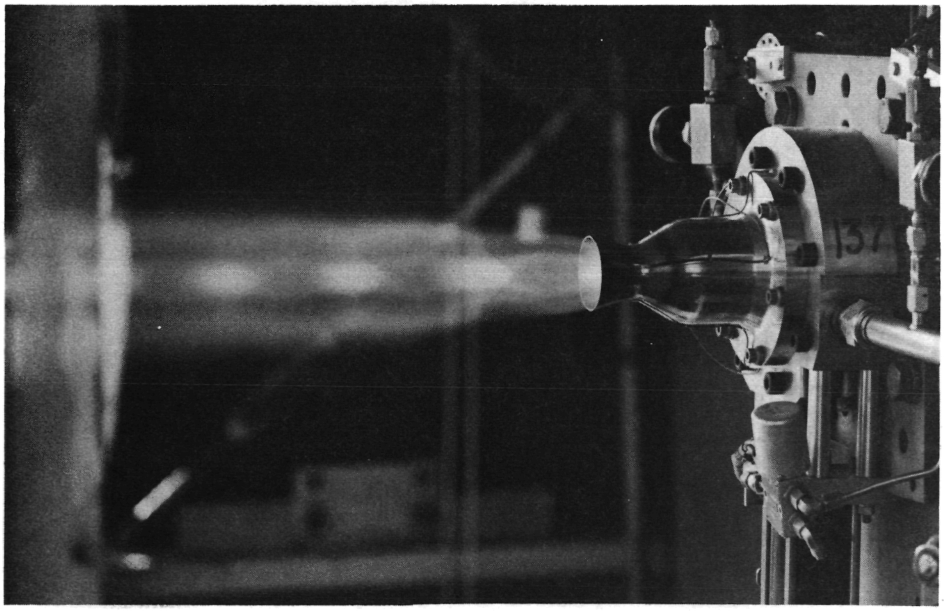
As part of a JSC study to identify viable alternatives to current Earth-storable hypergolic propellant combinations, a series of propulsion systems design and critical component design studies has been conducted, with emphasis on liquid oxygen (lox)/hydrocarbon (HC) propellants. In addition to being low cost and nontoxic, lox/HC propellants offer the required performance and bulk density for application to both orbit-transfer and Space Station propulsion systems. A broad matrix of hydrocarbon fuel and system design options was evaluated. Options included methane, propane, and ethanol as representative fuels, and pressure-fed, pump-fed, and integrated system propellant storage and feed configurations. Subscale injector (approximately 1000-lbf thrust level) and propellant cooling tests were conducted to verify critical engine design parameters. Ignition characteristics and thruster pulsing capabilities were defined using a flight-type 600-lbf thruster.

A prototype gaseous oxygen (gox)/ethanol thruster with a spark-initiated torch igniter was tested over a wide range of inlet conditions. The thruster was designed with a flight-weight thin-wall chamber/nozzle and flight-type propellant manifold volumes to acquire data on the pulse mode capability of a gox/ethanol reaction control system (RCS) thruster. Thruster tests were run using propellants at temperatures as low as -150° F.

The testing proved that the thruster was ignitible over the entire range of conditions tested. A typical gox/ethanol thruster firing is illustrated. Combustion was smooth in all tests. Exhaust plumes were clean with no evidence of soot or carbon deposition. Pulse mode capability was demonstrated; pulse durations as low as 40 msec were obtained with both ambient and cold propellants.

Thruster testing will be continued at the JSC Thermochemical Test Area (TTA) in late 1984 and early 1985. Pulse mode capability of the gox/ethanol thruster at altitude conditions will be demonstrated, and the ignition characteristics of ethanol, propane, and methane with lox and gox will be investigated. Also in the planning stages are tests using the lox/HC igniter hardware to evaluate the ignition characteristics of MMH (a non-hydrocarbon) with lox and gox.

Gaseous oxygen/ethanol thruster firing.



Low-Earth-Orbit Energy Storage Using Regenerative Fuel Cells

TM: J. Dale Denais/EP5
Reference OAST 2

The placement of a manned space station in low Earth orbit is being pursued by NASA as the next logical step in manned space flight. This concept will require multikilowatts of electrical power to perform routine orbital operations and such specialized functions as satellite servicing, space construction, and materials manufacturing.

In the past, all U.S. manned space programs except Project Mercury and the Skylab Program have used fuel cells because of their superior flexibility, weight, and cost factors. Fuel cells are the most viable power system candidates for short-term missions. However, the Space Station will require multiyear continuous power in an alternating daylight/nighttime environment. Solar panels are a solution to the daytime power requirements, and batteries have been the power source for nighttime conditions.

An alternate means of storing energy for nighttime low-Earth-orbit operation is being pursued. This approach consists of using a fuel cell that produces power and water during the dark side of the orbit combined with an electrolysis system that produces hydrogen and oxygen from the product water using solar-array-produced power on the light side of the orbit. These stored reactants are then reused by the fuel cell. This concept is called a regenerative fuel cell system. The use of regenerative fuel cells for energy storage is not only feasible but practical and advantageous in many areas. The advantages include high efficiency, low weight, potential for long life, good emergency capability, potential for weight-saving by integration with other subsystems, and the inherent capability to take advantage of reactant residuals from the Space Shuttle on trips to the Space Station.

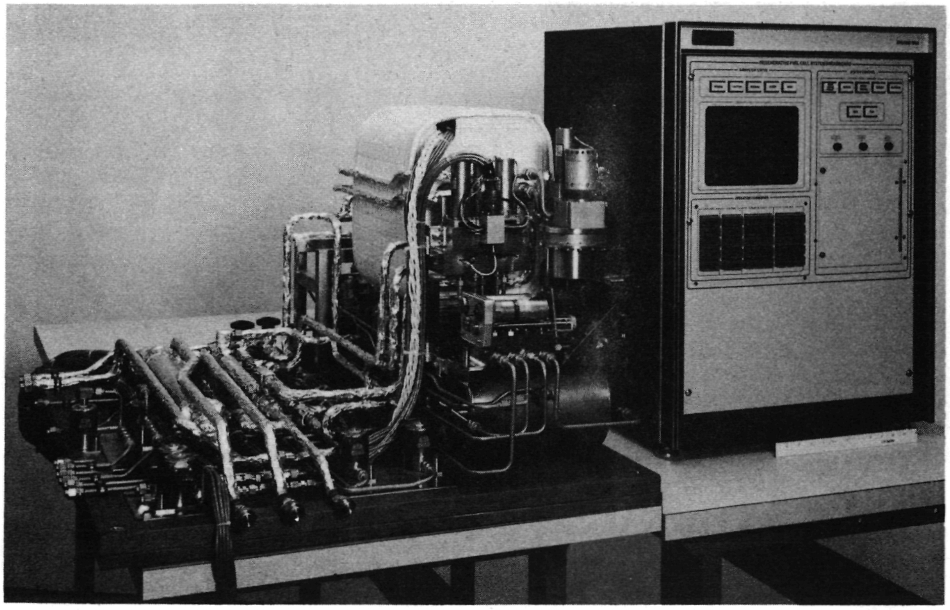
A joint effort between the NASA Lewis Research Center and JSC is under way to develop the technology of both the solid polymer electrolyte (acidic) and the capillary matrix (alkaline) regenerative fuel cells. Breadboard tests are being conducted at JSC to evaluate these technologies.

The solid polymer electrolyte breadboard system was delivered to JSC in February 1983 and was placed in simulated testing on May 6, 1983. The breadboard system was integrated with a 1.5-kW solar power station, a load bank, and a control and computer room. More than 1648 simulated orbital cycles have been accumulated on this regenerative fuel cell breadboard as of September 25, 1984.

Experience has shown that the solar power station can be connected to the electrolysis system directly with no power conditioning, a demonstration of the flexibility of the electrolysis system in handling a varying power input. Preliminary data show no measurable water loss, an indication that little or no makeup water will be required for multiyear operation in space. Test data have also verified that a 55%-efficient energy-in/energy-out cycle is achievable with existing technology and proper operating parameters. A continuation of this testing will reveal additional information beyond the demonstration concept phase.

The alkaline electrolysis breadboard is illustrated. The complete alkaline regenerative breadboard will consist of a static water-feed electrolysis unit and a Space Shuttle Orbiter-type fuel cell. This breadboard is in the final stages of testing at the contractor facility and should be delivered to JSC at the end of 1984.

Alkaline electrolysis breadboard.



STS Guidance And Control

TM: Paul C. Kramer/EH2
Reference OAST 3

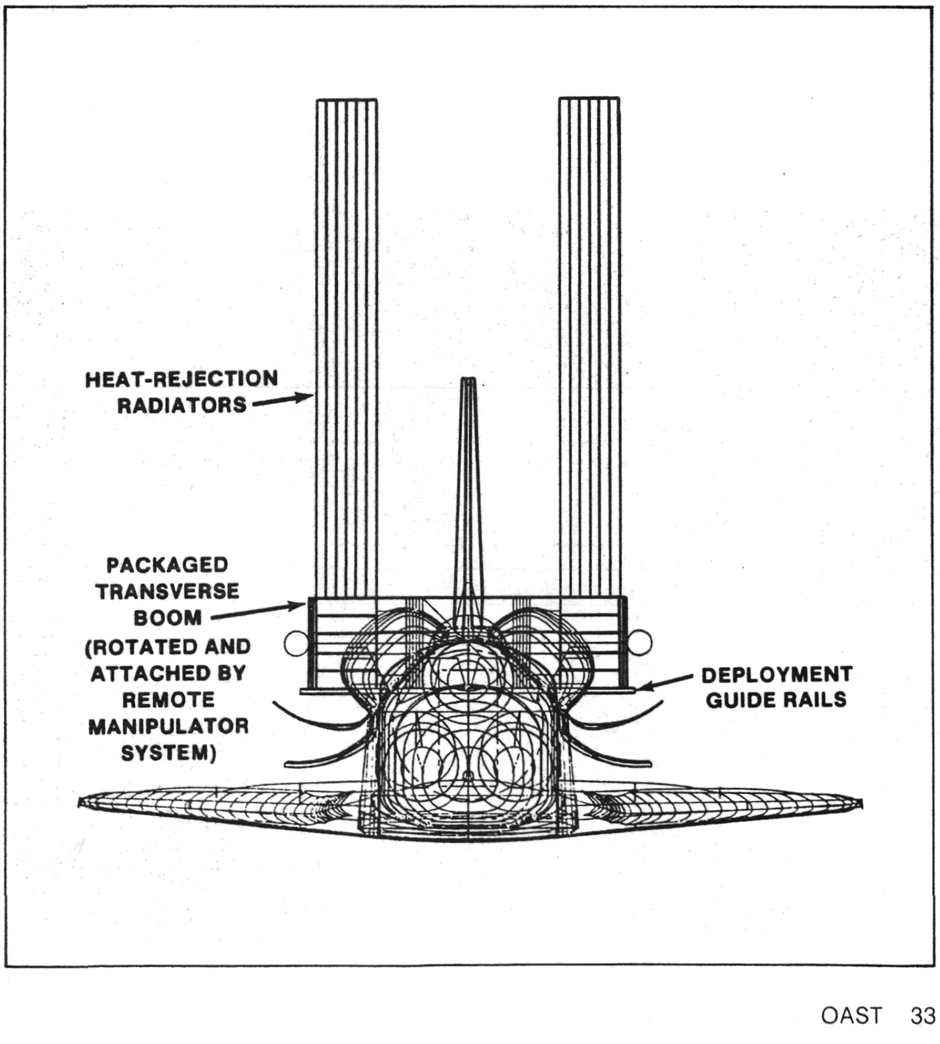
On-orbit operational experience in deploying and manipulating payloads of various sizes using the Space Shuttle Orbiter indicates a need to reduce the sensitivity of the control system to changes in the combined Orbiter/payload mass-inertia properties and center of gravity location. Present control system technology, as reflected in the Orbiter design, is limited in the range of these properties that can be accommodated without costly and time-consuming software changes. Also, the requirement to ensure adequate stability and efficient performance with vastly different payload mass-inertia properties results in a relatively long-term, sustaining engineering force during the operation phase to assure payload and flight control system compatibility on a mission-by-mission basis. Advanced vehicles such as Space Station will entail much larger changes in configuration characteristics during buildup, with larger uncertainties than ever before.

The JSC has initiated a technology advancement program to develop the requirements and create a typical flight control design that is inherently adaptive to large variations and uncertainties in mass-inertia properties, control effector configuration, and external disturbances such as aerodynamic and gravity gradient torques. The program approach is to investigate methods for reducing the potential for dynamic interaction within an Orbiter-type digital autopilot, to determine the expected variations and uncertainties of the driving parameters for future vehicles, to develop new methods for providing traceability of design driving requirements through all levels of software and design implementation documentation, and, finally, to apply the resulting design concept improvements to a control system design problem for a typical large, flexible spacecraft. Four specific study areas are required: (1) definition of the limit of the present control envelope, (2) development of a new method for software requirements documentation and control, (3) definition of the scope of the requirement for adaptive control through long-range planning studies, and (4) development of requirements and software models for a large vehicle control system that is autonomously adaptive to all rigid-body and external disturbance parameters.

Parametric study of the Orbiter control system indicates several design areas that could be modified to significantly improve stability, e.g., in the hardware area, replacement of the inertial measurement rotational state estimator with ideal rate-gyro information could improve stability and performance. As a result, consideration will be given to integrating the existing rate gyros (sized for ascent and entry) into the on-orbit control systems. Several software improvement concepts were investigated including a new automatic maneuver routine algorithm, which will be evaluated with system uncertainties.

Long-range planning studies have addressed the need for improved on-orbit control systems. The published document "A Strategic Plan for Rendezvous and Proximity Operation" addressed the needs and proposed approach for integrating the technology and advanced development activities across project and program lines for the various space systems involved with integrated orbital operations. As a result, a major effort is under way to implement an NASA intercenter rendezvous and proximity operations workshop.

Early Space Station deployment/buildup concept illustrating the effect of operational configurations on stability limits.



Man-Modeling of Human Factors for Crew Interfaces in Space

TM: Barbara Woolford/SP22
PI: Martin Altschuler and Normal Badler
Reference OAST 4

Designing the interfaces between a spacecraft and its crew requires thorough knowledge of human characteristics and capabilities. The size of an individual can determine whether an area or an instrument is accessible. Such factors as the distance a person can reach and the speed at which he or she can move must be considered when a work station is designed or a task is planned.

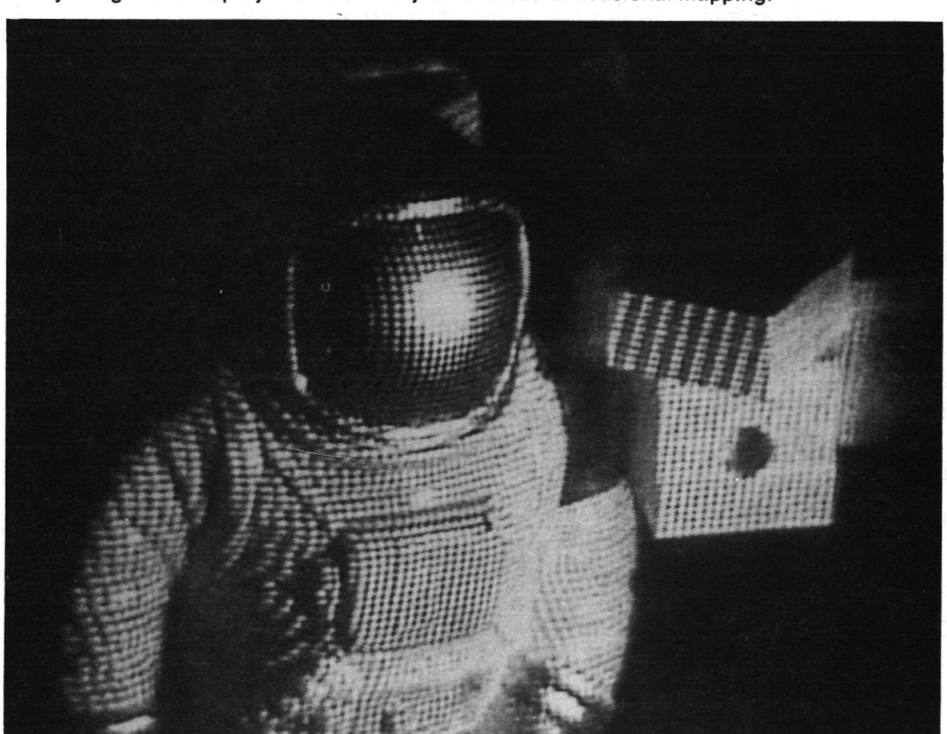
Design techniques which were done primarily with a drawing board and mockups are now being done with computer aided design (CAD) tools. With highly advanced computer graphics, it would seem that the modeling of human bodies would not be a problem. However, getting the numerical data to describe the irregular shape of a human is difficult. The principal current technique used to obtain such data is stereophotogrammetry, in which two photographs are taken of a body from different positions. Matching points on the images are digitized, and the three-dimensional location is obtained by triangulation. The engineer must do the digitizing to identify the matching points. If the matching points could be identified automatically, the process could be performed by a computer in a matter of minutes.

The primary task has been the development of models describing human anthropometrics, kinematics, and dynamics in an interactive computer environment. These tools will enhance the CAD system being developed in-house. The laser-based anthropometric measurement system (LAMS) replaces one imaging camera with an "active camera." The LAMS is actually an array of light beams generated with a laser. Mathematically, a ray traveling from a point on a plane through the focal point of a lens to an object is equivalent to a light beam reflected from an object through a lens to a plane. The LAMS generates an array of 128 by 128 beams which are projected onto an object. An array of discrete beams illuminating an astronaut doll is illustrated. The rays pass through a shutter which can pass or block each column of light. By use of eight exposures, the origin of the column of beams can be coded. On the first exposure, all the beams are on; on the second exposure, only half the beams are on; and so on down to the eighth exposure, in which alternate beams are on.

The reflected rays are captured by a video camera and the image is automatically digitized. The eight pictures are compared automatically to identify which beam reflected to which point in the video image. Once this correlation is known, standard triangulation techniques are used to calculate the actual (X, Y, Z) locations from the picture location and the beam column location. The computer calculates and stores the location of each of the 16 000 points which define the surface of the body. Further processing results in smoothing and connecting the data points and thereby generating a graphical image. By integrating pictures taken from several viewpoints, the whole body can be mapped. Human motion modeling requires that the graphical body be modeled with joints, which can then be rotated to produce a representation of human movement.

This year, an entire body was mapped for the first time. Although the data collection process still requires several minutes, a new high-speed shutter and multiple cameras and light projectors will shorten the time. The data processing algorithms have been developed for calibration and triangulation. Generating a graphical image from 16 000 data points is still a manual process, but work is under way to automate that critical step. The following step of identifying body parts and modeling joints remains to be accomplished.

Array of light beams projected on an object for three-dimensional mapping.



Multifunction Synthetic Aperture Radar Technology

TM: Kumar Krishen/EE4
Reference OAST 5

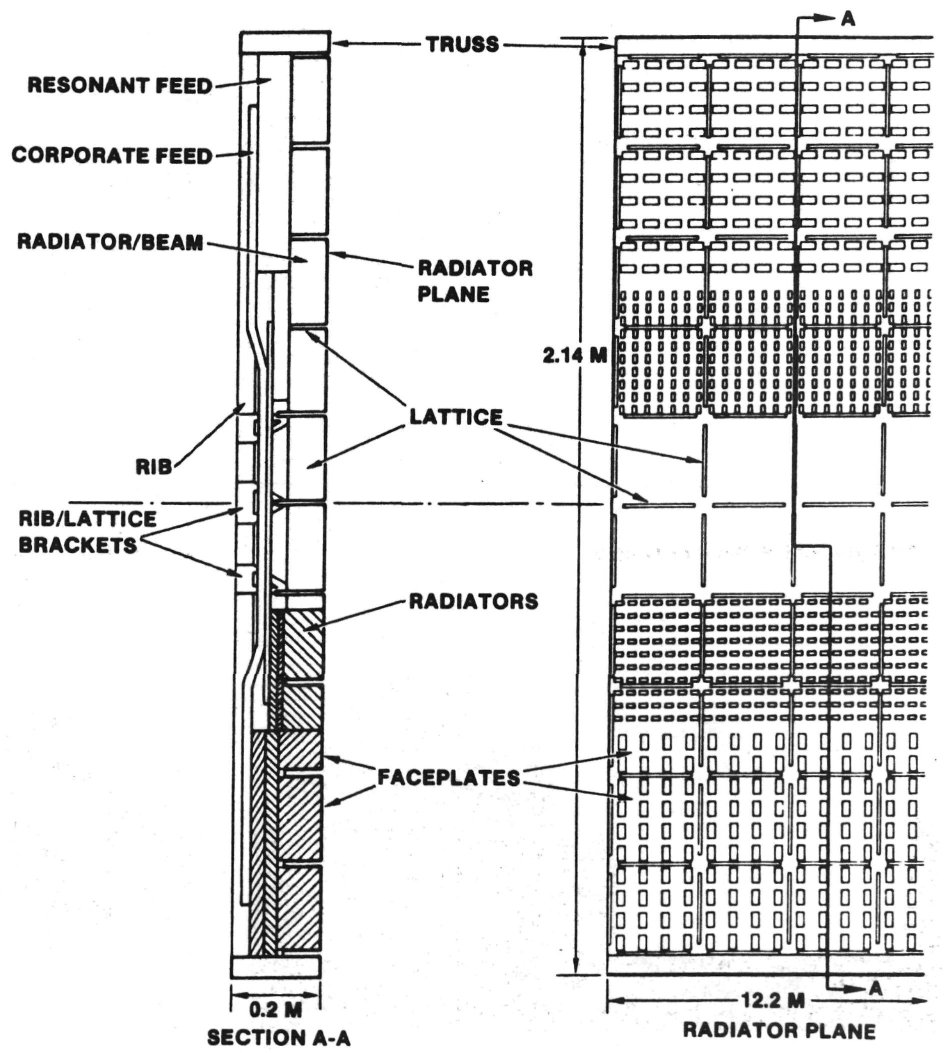
Significant progress has been made in identifying the information needed for understanding the processes that underlie modifications of the Earth surface. These processes determine the global distributions and the dynamics of biological productivity. The very frequent need for parameters used in biological predictive models has given impetus to remote sensing using synthetic aperture radar (SAR) systems. Aspects of the vegetative, surface, and subsurface phenomena not otherwise accessible to remote sensing are ascertainable through high-resolution SAR data alone or in conjunction with observations in the visible and infrared spectral bands. In addition, SAR's have been established as a unique means for obtaining nearly all-weather data on ocean phenomena. The SAR mission set for the 1980's and 1990's includes Shuttle Active Microwave, Venus Orbiting Imaging Radar, Ice Satellite, U.S./Canadian SAR, and Free Flying Imaging Radar Experiments. The functional requirements for future SAR missions include swaths in excess of 150 km and multiband, multipolarization, and multi-incidence-angle capability with amplitude calibration to approximately 2.0 dB. New technology advancements are needed in the areas of (1) antennas capable of operating at several frequencies with electronic beam steering and multipolarization capability and (2) subsystems and techniques for SAR calibration.

The approach to antenna technology is to perform tradeoff studies to identify the most feasible and efficient designs. Two such designs have been identified as a result of fiscal year (FY) 1983 and FY 1984 efforts. These design configurations are the microstrip distributed array and the interleaved waveguide array. A dual-frequency/dual-polarization microstrip antenna was developed as a stacked configuration. The performance of this breadboard was unacceptable. In FY 1984, a side-by-side microstrip antenna design was developed. This antenna can operate at L-, C-, and X-band frequencies. The implementation of this multiband antenna was developed for the C-band frequency. A breadboard of the C-band distributed-array (12 by 18 elements) antenna has been developed. This breadboard is being modified to incorporate distributed power design. After successful completion of this task, a breadboard panel of the multiband antenna will be developed and tested.

The interleaved-array antenna design concept has been developed for the multiband antenna. A survey of materials suitable for spacecraft design was completed. The application of graphite epoxy for the design was established through construction and testing of waveguide and feed components. These assembly techniques are being demonstrated by fabrication of a 5 by 5 array at X-band frequency. Development of a breadboard array at L- and C-band frequencies is planned to verify the overall antenna design and fabrication feasibility.

In the area of SAR calibration, detailed procedures and approaches were documented. Computer simulations for developing performance parameters were completed. The antenna beam steering was implemented using simulation of a phased array. The effects of beam steering on grating lobes were studied. Functional check-flight data acquired by the U.S. Air Force aircraft SAR test bed were analyzed. This SAR test bed incorporates a unique calibration subsystem, which can be applied to NASA SAR designs. The overall procedure for SAR calibration is being developed on the basis of data analysis results.

Interleaved-array antenna fabrication configuration.



Magnetic Bubble Memory System Development

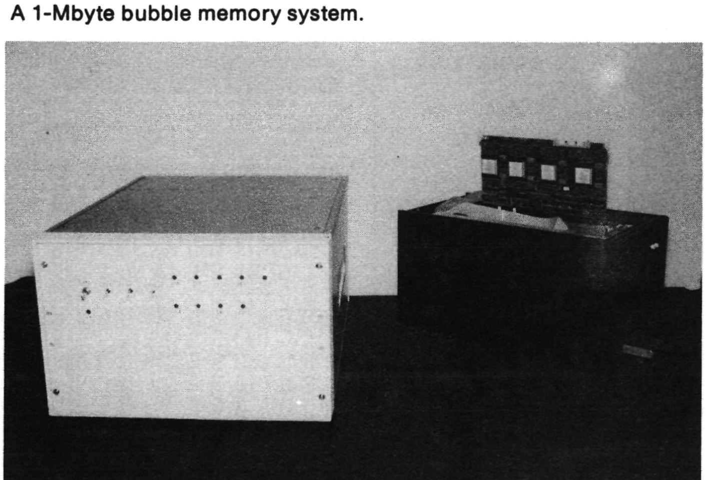
TM: Edgar A. Dalke/EH4
Reference OAST 6

The JSC is continuing to investigate the use of magnetic bubble memory device technology for space-flight system applications requiring nonvolatile mass memory. The initial effort was aimed at the development of a magnetic bubble memory system which could replace the existing Space Shuttle Orbiter mass memory unit (MMU). Using off-the-shelf devices, a breadboard unit, with 1-Mbyte capacity, was fabricated and demonstrated to be operationally transparent to the Orbiter software system which controls the existing magnetic-tape MMU. Subsequent emphasis has been on the development of a 16-Mbyte mass memory system capable of being physically packaged with the dimensions of the Orbiter MMU.

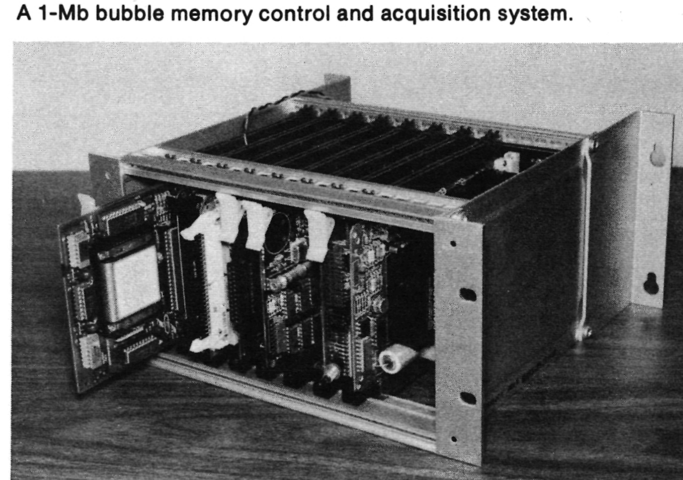
A 16-Mbyte magnetic bubble memory system dictates the availability of devices with a density that approximately quadruples the capacity of the present 1-Mb devices. Estimates from industry indicate that sample units having sufficient capacity will be available by the end of 1984. The JSC approach also involves the design and development of a custom interface controller having sufficient throughput, intelligence, and high-speed memory to enable the mass memory system to support the Orbiter MMU requirements as well as the functions of a file server in a distributed data base environment. Subject to the availability of the higher density devices, a 16-Mbyte system will be developed and integrated into a data management system test bed to demonstrate the concept of interactive and distributed data base operations as perceived for the Space Station.

The project activity currently is oriented toward packaging the bubble devices into a prototype flight configuration, along with the development of necessary software and system interfaces to support investigation of distributed spacecraft system processors in a local area network (LAN) environment. The original breadboard (left) alongside the upgraded unit which employs the custom controller and 1-Mb devices (upper right) is illustrated. Another adaptation of magnetic bubble memory device technology for space systems is also shown. The configuration shown uses a 1-Mb device to provide nonvolatile mass storage in a special control and data acquisition system which can support the needs of small experiment payloads on the Orbiter or in the future Space Station.

A 1-Mbyte bubble memory system.



A 1-Mb bubble memory control and acquisition system.



Space Station Communication and Tracking Technology

TM: Kumar Krishen/EE4
Reference OAST 7

Space Station communication and tracking technology development is required to minimize operational constraints and cost of operations while providing the capability for cost-effective modular growth. The initial operational configuration (IOC) technology target areas are antenna, radiofrequency (RF), and television systems, laser ranging and tracking, and signal design.

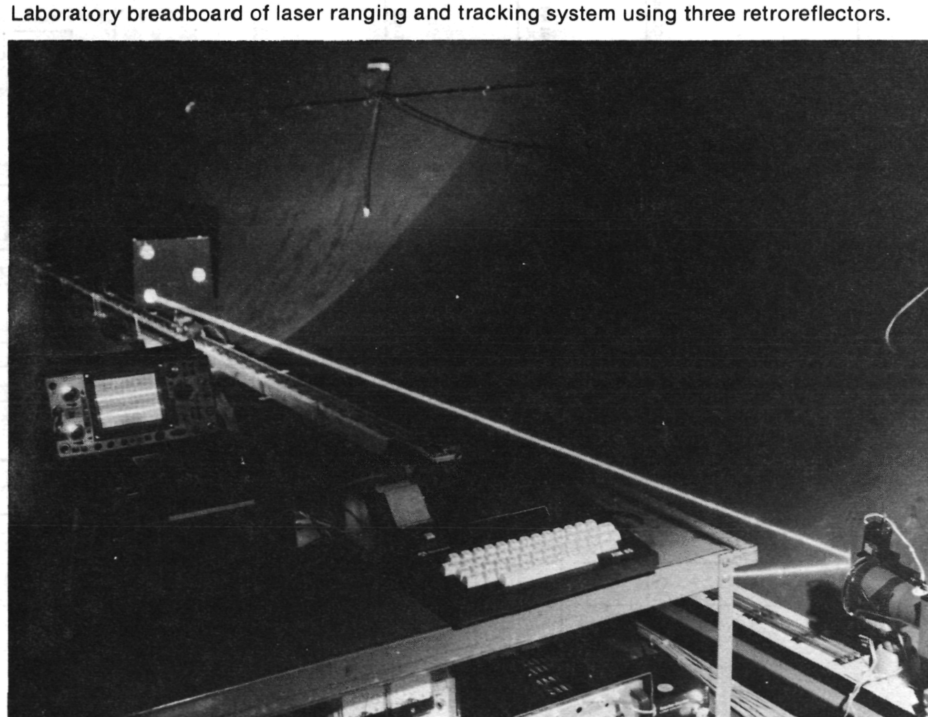
Antenna technology development is aimed at minimizing the number and size of antennas while providing spherical coverage, simultaneous links to several near and far users, and broadband coverage (S-, X-, and K_W-bands). The RF system designs must be optimized in frequency assignments and coding schemes to achieve higher performance in power levels, sensitivity, and dynamic range. Television systems will be important in many operational aspects of the Space Station and are anticipated to encompass image processing for automation and proximity operations. Advanced, more efficient systems with greater reliability are required. Automatic soft docking will require sensor performance beyond that currently available in microwave systems.

In antenna technology, coverage and obscuration analyses are being conducted on representative Space Station configurations as an aid in establishing overall requirements. Multiuse antennas appear to offer the potential for minimizing the size and number of antennas needed without creating operational compromises. Optical ranging employing laser transmitters and receivers should provide the necessary accuracy for short-range stationkeeping and soft docking. In these and all other critical subsystem areas, the technology program is intended to create design concepts and alternates which can be developed into breadboards for laboratory evaluations. As the Space Station Program progresses, these subsystem breadboards will be available for integration into a more elaborate system-level laboratory configuration for test and evaluation of end-to-end performance.

A laboratory breadboard of a laser ranging and tracking system was completed and tested this year. Design deficiencies in several areas have been identified. During fiscal year 1985, design changes to the breadboard system will be made and evaluated. Alternative designs will also be explored to reach the optimum sensor system. In addition, two design alternates of a multibeam/multiband antenna have been identified. A similar design process has been completed for an advanced television system. Design refinement and breadboard development will be initiated on these elements in fiscal year 1985.

Various coding and modulation schemes will be evaluated to support signal design and to resolve major issues of RF interference resistance and efficient multiaccess capability. Accomplishments to date include the development of detailed mathematical models and simulations of the noise and interference environment.

Laboratory breadboard of laser ranging and tracking system using three retroreflectors.



Orbiter Experiments Integrated Systems Test

TM: R. L. Spann/EX3
Reference OAST 8

The Orbiter Experiments (OEX) Program uses the Space Shuttle Orbiter for acquiring information to develop and authenticate various aerospace vehicle design parameters. Some experiments have been perfected and others are being designed to exploit this unique research capability. Several OEX's, the SILTS, the SUMS, the Aerodynamic Coefficient Identification Package/ High-Resolution Accelerometer Package (ACIP/HIRAP), and the SEADS, have been installed into the Orbiter *Columbia* for flights planned to begin in May 1985.

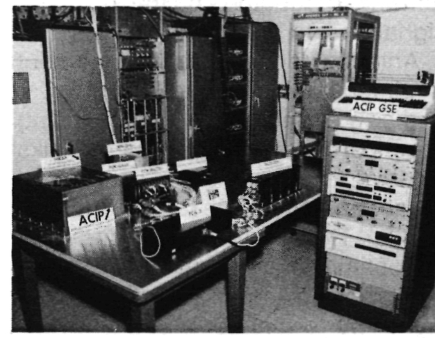
As the experiment integration activity intensified, questions arose as to the compatibility of the experiments with each other and with the onboard Orbiter data and power systems. The questions encouraged the creation of an integrated systems test wherein these concerns could be addressed in a laboratory environment.

An electrically integrated system was developed which included the previously mentioned experiments and support systems. The support systems included (1) the system control module (SCM), which effectively provides the interface between the Orbiter systems and the OEX systems, (2) the pulse code modulation (PCM) master/slave system, which interfaces certain experiments with the OEX control unit, and (3) the support system for OEX (SSO) composed of the tape recorder, an interface and control module, and a PCM system.

The integrated systems test is illustrated as physically and schematically configured in a JSC laboratory. The use of this facility, which has a simulated Orbiter ground plane and power system, together with the use of flight equipment support systems minimized the need for acquisition of additional hardware to support these tests.

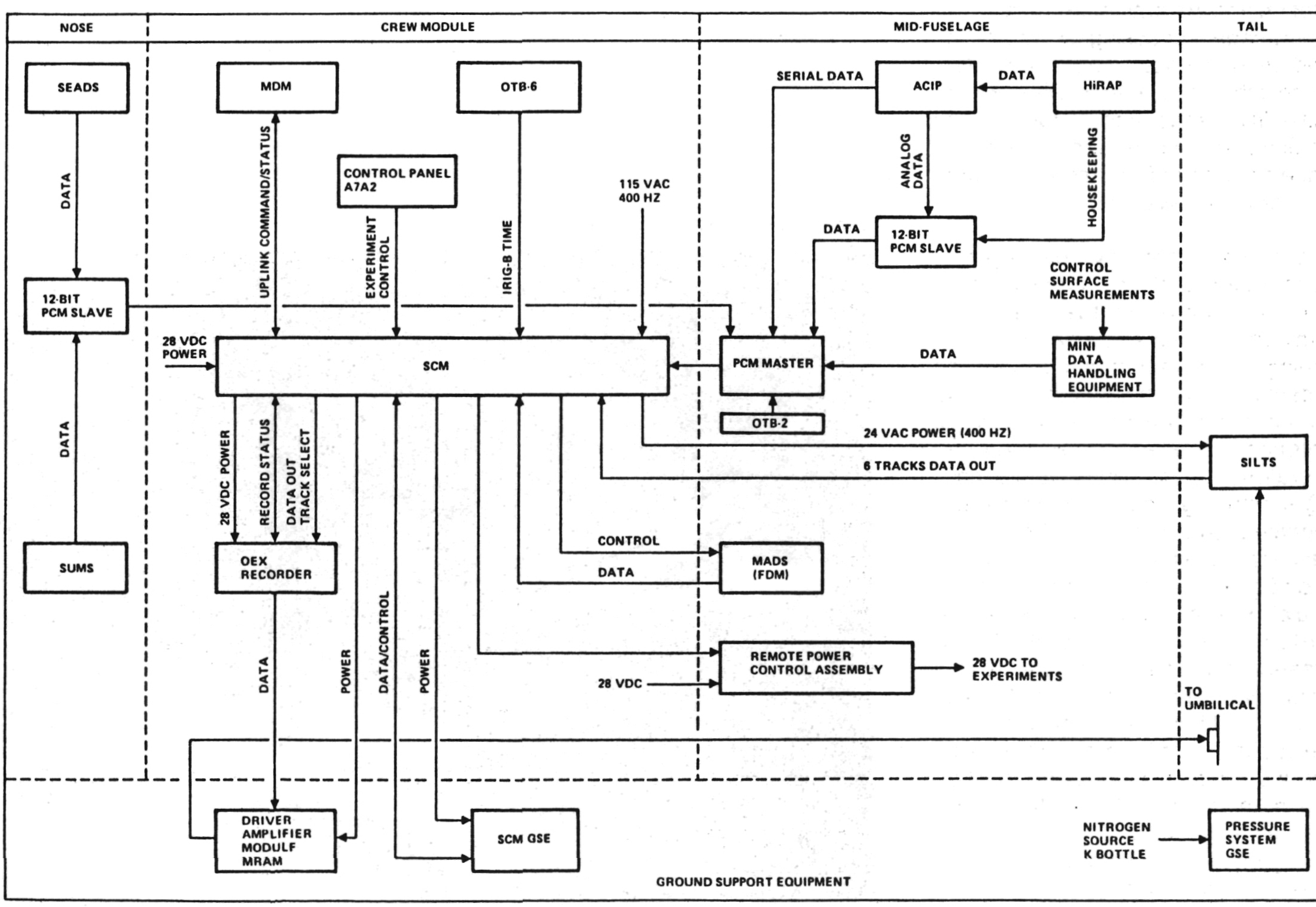
Systems testing was performed under both nominal and off-nominal conditions. Off-nominal conditions included nonroutine experiment turn-on sequences and off-nominal voltage levels which included surges.

The test results were positive and thus demonstrated that the OEX's will operate within specification under the most severe conditions.



OEX integrated systems test apparatus.

Schematic diagram of OEX integrated systems test.



Atomic Oxygen Interaction Studies

TM: L. J. Leger/ES5 and J. T. Visentine/ES5
Reference OAST 9

As a spacecraft orbits the Earth at an altitude of 300 km, its surfaces are exposed to an impingement flux of 10^{15} particles/cm^2-sec, most of which is atomic oxygen. Since atomic oxygen is a strong oxidizing agent and has a large kinetic energy due to vehicle movement, exposed organic surfaces undergo significant recession. The recession rates experienced on Space Shuttle vehicles indicate that exterior coatings on long-lived spacecraft, such as Space Telescope and Space Station, will need to be selected for durability to atomic oxygen effects. Quantitative measurement of recession rates or interaction rates is necessary to properly predict and compensate for this phenomenon.

After the discovery of atomic oxygen effects on the early Space Shuttle flights, experiments were conducted to measure reaction rates for typical exterior coatings. The first atomic oxygen experiment in which a large number of materials were exposed was conducted on the fifth Space Shuttle flight (STS-5). Results obtained from this experiment (reported last year) verified previously observed flight effects and provided quantitative reaction rates for some materials, principally thin films.

An opportunity for an additional flight experiment was presented on STS-8. With the experience and interest gained on STS-5, a new experiment was developed with the objectives of extending the quantitative reaction rate data base, confirming the effects of temperature, and preliminarily evaluating the effects of solar ultraviolet light and ambient plasma on reaction rates. Fifteen organizations participated in the experiment.

The experiment samples and special hardware were mounted on two trays in the Orbiter payload bay, as illustrated. The first tray was used primarily for the disk samples. Sections of tethered satellite candidate Kevlar cables were mounted on the edges of this tray, as well as on a special mounting device which exposed larger sections of cable for strength evaluations. Additional samples on this tray consisted of larger sections of Kevlar, glass fabric, and a micrometeoroid collector with special coatings for protection from oxidation.

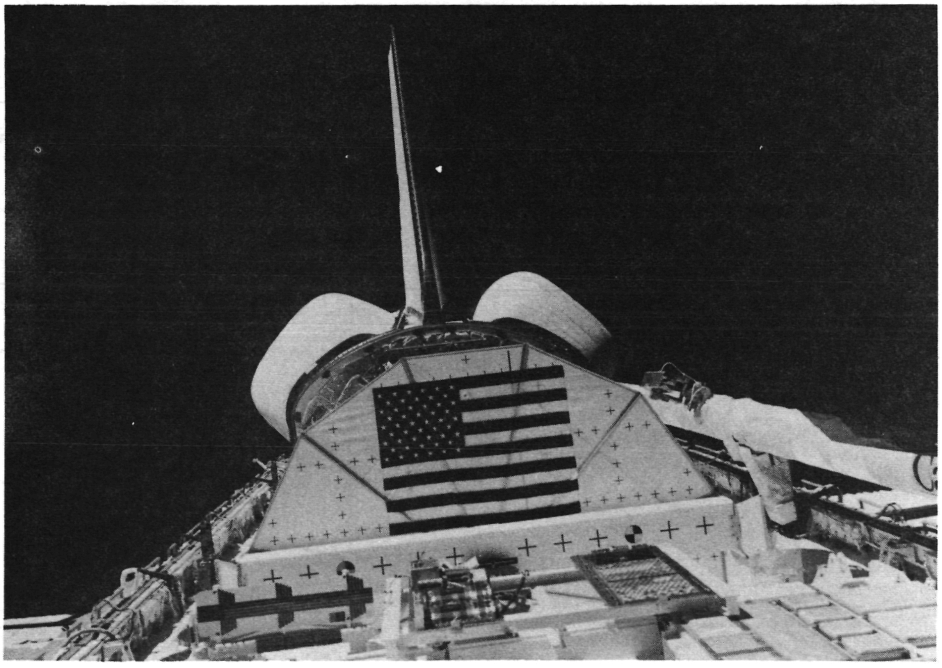
The second tray contained experiments which were active during flight. Both power and in-flight crew switching capability were provided. Experiments mounted on this tray provided information on (1) the effects of temperature and solar exposure on reaction rates, (2) the effects of plasma as derived from samples mounted under gold and Kapton, (3) the effects of oxidation on thin silver films, and (4) the mass transfer of oxidation-condensable products onto collector surfaces.

The samples were exposed to atmospheric ram conditions by orienting the vehicle at an altitude of 225 km to an attitude with the payload bay pointing into the velocity vector. Maintenance of this orientation for 41 hr resulted in a total atomic oxygen fluence (integrated flux) of 3.5×10^{20} atoms/cm^2. This fluence is the highest obtained on an atomic oxygen experiment to date and corresponds with the approximate fluence to which Long-Duration Exposure Facility (LDEF) flight samples will be exposed on the forward facing, or ram, side.

Since total surface effects are proportional to fluence, large changes occurred, such as the complete removal or oxidation of films of Mylar 12 to 13 μm (0.5 mil) in thickness. Quantitative reaction rates were obtained for a large sampling of typical spacecraft materials. The effects of heat and solar ultraviolet radiation on reaction rates appear to be minor, and no plasma-related changes were noticed.

In general, organic materials containing carbon, hydrogen, oxygen, and nitrogen have the highest reaction rates (2×10^{-24} to 3×10^{-24} cm^3/atom). Prefluorinated and silicon-containing organic materials have reaction rates that are lower by a factor of 10 or more. Some metals, notably silver and osmium, are also very reactive.

Deployment of STS-8 Atomic Oxygen Experiment. Thin-film and disk specimens are shown in the foreground (below the flag). Strips of Space Telescope material to support induced-luminosity studies are shown attached to the remote manipulator system (right of flag).



Space-Constructable-Radiator Thermal Vacuum Test Program

TM: Paul F. Marshall/EC2
Reference OAST 10

Unique thermal management requirements imposed by the Space Station, such as high heat loads, long transport distances, and long operating life, have created the need for technology development in heat rejection. Since 1979, JSC has been conducting a program to develop a modular heat pipe (HP) radiator subsystem for Space Station application. The major thrust of the technology program to date has been to improve HP capacities to accommodate the radiator application. After the performance capabilities of the baseline HP design were demonstrated in laboratory tests, KC-135 tests, and a Shuttle flight experiment, two full-size prototype radiator elements were fabricated and tested in JSC thermal vacuum facilities to complete the technology demonstration phase.

Two prototype HP radiator elements were built to support the thermal vacuum performance demonstration. The central element of each unit is the dual-passage monogroove ammonia HP. Both radiator elements were configured in a "U" shape to accommodate test facility size constraints. Both panels have 20 ft of condenser length along each leg connected by an adiabatic section approximately 25 in. long. The radiator surfaces for each unit are of a simplified monocoque design with the HP located down the centerline. The fin was painted white to provide desirable radiator surface properties.

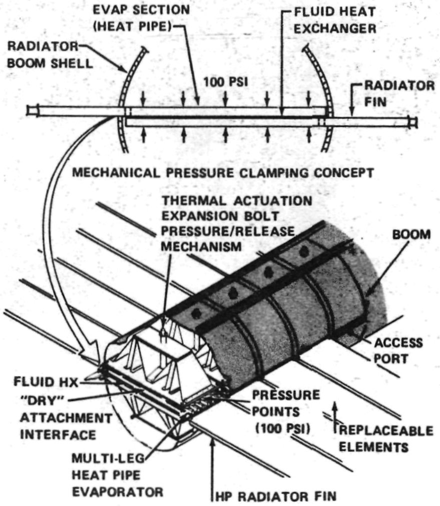
The two prototype units are distinguished by their respective evaporator configurations. The first has a six-legged monogroove HP evaporator/manifold assembly welded to the end of each condenser leg. The heat exchangers (HX's) for both evaporators are brazed directly to the evaporator HP's to represent the fixed, non-space-constructable, body-mounted concept applicable to Space Station module surfaces. The other element has a six-legged evaporator assembly on the end of only one condenser leg to represent the space-constructable application. This evaporator interfaces with a contact HX assembly, which uniformly distributes a mechanical load over a large area to clamp the supply HX to the evaporator surface. The assembly also is capable of relieving the clamping load to enable assembly and disassembly of the radiator system.

The two elements were placed in the test chamber side by side on support stands which provided very close tolerance leveling and a remotely actuated tilting capability. The overall test approach was to impart heat loads to the evaporator section of each element through a Freon-21 fluid circuit, controlled externally. This approach provided the capability to operate the radiator elements over a broad range of heat loads and temperature levels.

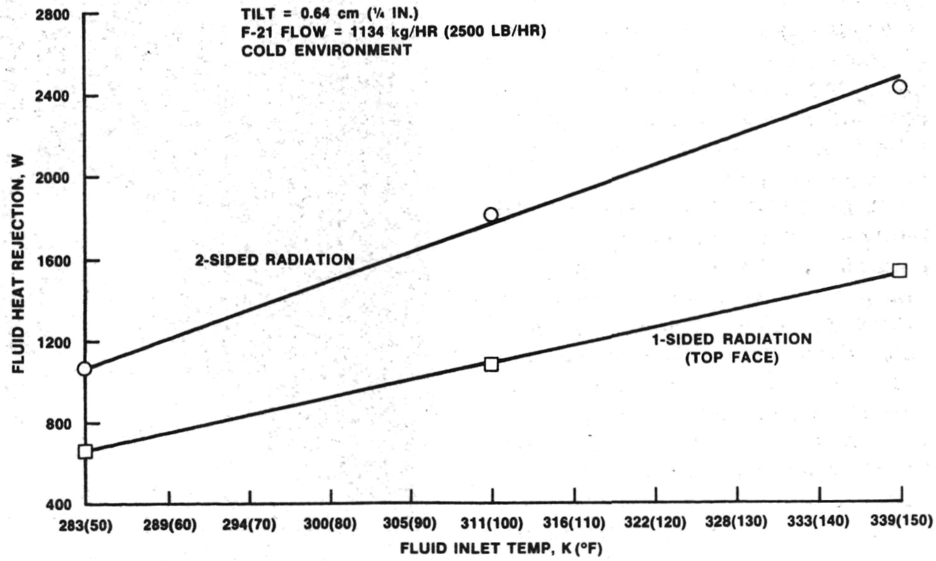
The 4-week test sequence was completed in June 1984. A broad definition of performance characteristics included the following.

1. A complete steady-state performance map was generated for each element over the temperature range of 50° to 150° F at incident thermal environments representative of low Earth orbit. The maps included HP performance at adverse tilt and one-sided and two-sided radiator modes. The maximum heat rejection achieved in the two-sided mode was 2.5 kW.
2. The contact HX assembly was tested over the entire temperature range. The average conductance observed was in the range of 250 to 300 Btu/hr-ft^2 for the contact assembly with a "dry" interface and on the order of 500 Btu/hr-ft^2 for the "wet" interface. Also, the clamping and release capabilities of the HX assembly were demonstrated.
3. The HP's were allowed to freeze several times to investigate the recoverability of inactive panels. Thawing was demonstrated using simulated solar heating under several different conditions. In particular, the capability to thaw under load and under low-temperature conditions was demonstrated.

Space-constructable-radiator interface concept.



Prototype radiator typical performance.



Space Sciences and Applications

Solar System Exploration

Summary

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Office of Space Sciences and Applications

Summary

Solar System Exploration

The major thrust of solar system exploration at the Johnson Space Center (JSC) is research on the inner planets, asteroids, comets, and other small bodies, through laboratory analysis of extraterrestrial samples, experimental simulations, and flight experiments. This work is synergistically integrated with studies of the origin and evolution of the Earth's crust to provide a more complete understanding of all aspects of planetary evolution. In addition, research is being conducted to better understand the near-Earth space environment and the impact of Space Shuttle and other industrial activities on space and the upper atmosphere. Definition of future scientific exploration and use of the Moon continues. Such exploration is anticipated to be a major NASA program within the next two decades. Highlights of recent JSC research are described in the following summary.

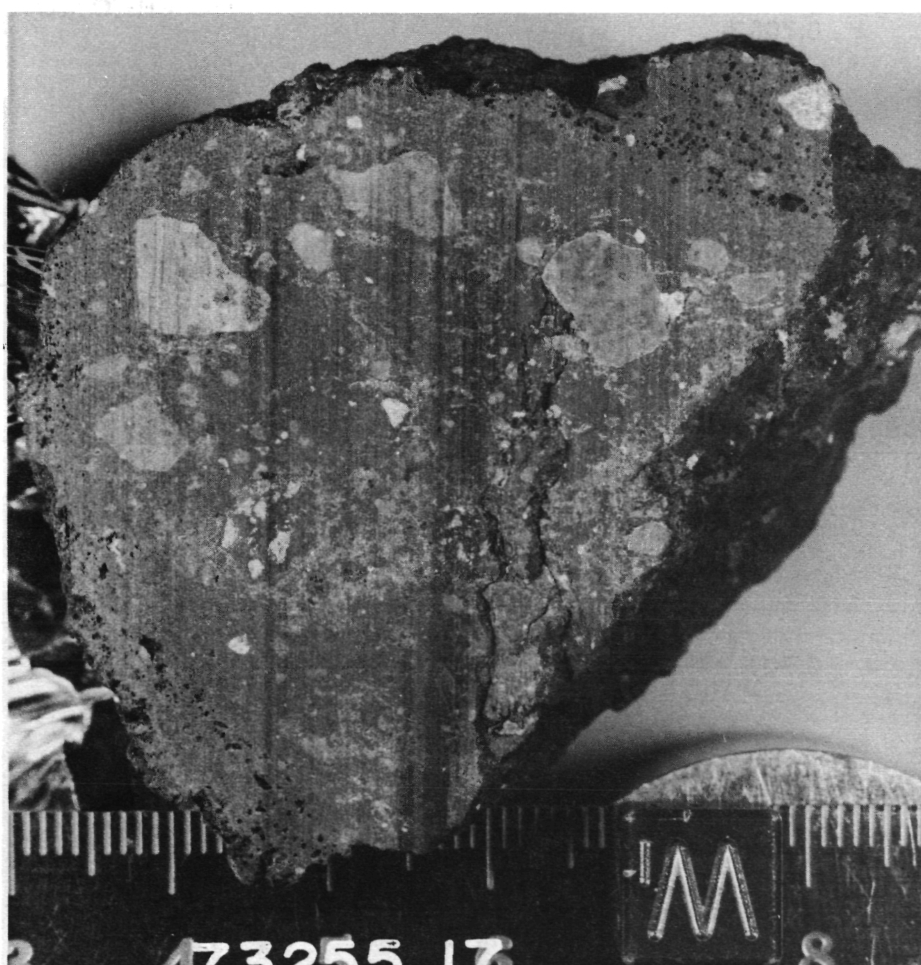
Lunar Science

Lunar samples, a legacy of the Apollo Program, have been an invaluable source of new information about planetary processes. Many of our ideas about such diverse processes as the formation of crusts and mantles, the effects of large impacts, and the development of planetary regoliths are outgrowths of the study of lunar samples. Even 15 yr after the first lunar samples were collected, detailed study of newly released samples or of material recently exposed by new saw cuts continues to produce significant discoveries that underscore the value of continued analysis long after the operational phase of a mission has ended.

One reason that lunar samples continue to reveal new information is the complexity of the samples. Most of the larger samples are of a rock type called breccia. Breccias are composed of fragments of a wide variety of rocks of different origins which have been fractured, transported, and reconsolidated by repeated impact events during the first half billion years of lunar history. Thus, a single breccia, as illustrated, usually contains samples of many rock types, each of which reveals information about the evolution of the Moon.

During the past year, continued emphasis has been placed on obtaining new types of lunar materials within the JSC lunar sample collection by slabbing several of the large breccia samples. New surfaces have been created, and several consortia of lunar scientists have been organized to map, sample, and study these surfaces

A sawn surface of lunar breccia sample from Apollo 17. The irregular-shaped light-colored objects are fragments of many different rock types. The medium gray matrix which contains the fragments is impact-produced melt. The frothy rind around the sample is a coating of melt from the last major impact event to affect this sample. Detailed study of the lithic fragments from breccias such as this one continues to reveal new rock types and to provide important new information about the origin and evolution of the Moon.



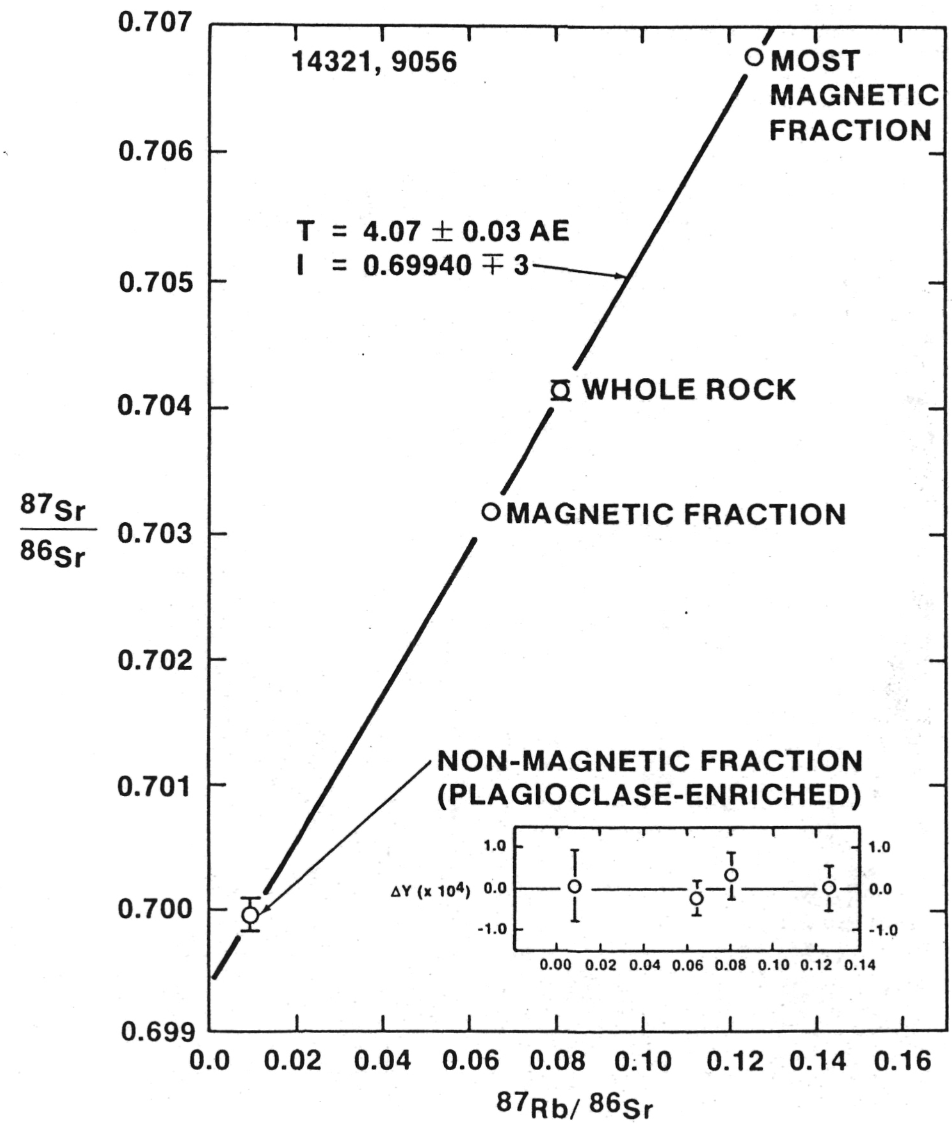
in detail. Material taken from the new surfaces has been the object of intensive study. These investigations have revealed new rock types that place additional constraints on the time scales and petrologic processes which produced volcanic rocks on the Moon. One new type is similar in composition to previously studied lunar basalts (rocks formed when molten lava cools), except that it has much higher content of potassium (K) and rubidium (Rb). Normally, enrichment in these elements is accompanied by characteristic enrichment in another group of elements, the rare earth elements (REE). Decoupling of enrichment of K and Rb from REE in these samples indicates that their formation was affected by processes which have not been seen in other basalts and are not yet well understood.

Another new group of samples exposed by the slabbing of an Apollo 14 breccia is an aluminum-rich variety of basalt. Radiometric dating of one of these samples revealed an age of 4.07 Gyr and an initial strontium (Sr) isotopic ratio that is clearly distinct from other previously studied Apollo 14 basalts. Thus, continued study shows that the lunar sample collection contains a far greater variety of rock types than first thought and that further detailed study of new rock types seems certain to modify current ideas concerning lunar petrogenesis.

Active JSC lunar sample study during the past year also involved analysis and dating of zircon crystals in lunar samples. Dating of most ancient lunar crustal rocks by conventional techniques is difficult because most radiometric ages have been disturbed by the intense impact activity, which did not subside until about 500 Myr after the Moon's formation. However, zircon is a mineral which is known from terrestrial studies to be resistant to melting and chemical alteration. In terrestrial rocks, zircons often preserve their original ages of crystallization from melts, even though subjected to subsequent episodes of heating and metamorphism. Zircons from five lunar samples were selected and chemically analyzed at JSC and, then, radiometrically dated using the ion microprobe at Australian National University in an effort to look back through the impact events to the time of original formation from melts. Dates for all five samples were about 4.4 Gyr. Zircons do not crystallize until late in the solidification of any magma body. The very old ages of these zircons therefore indicate that the process of differentiation which formed the lunar crust was completed within 100 Myr of the formation of the Moon. If substantiated by additional work, these old ages will place major constraints on models for the thermal evolution and early chemical differentiation of the Moon.

Another recent JSC study has contributed to our understanding of the mechanical and chemical evolution of the layer of fragmental debris at the lunar surface called regolith. This layer was formed by the repeated bombardment of surface rocks by relatively small meteorites, which gradually eroded the larger rocks and formed a fine-grained soil. Details of regolith formation have been studied theoretically, and the effects of single impacts are reasonably well understood, but no information was previously available regarding the effects of repeated impacts in the same target material. The JSC experimental study involved impacting the same initially hard, gravellike target material 200 times with high-velocity projectiles. One important finding of this study

Rb-Sr isochron diagram for an aluminous mare basalt clast from Apollo 14 lunar breccia 14321. The isochron is the straight line along which lie measured values of the isotopic ratio $^{87}Sr/^{86}Sr$ and the atomic elemental ratio $^{87}Rb/^{86}Sr$ for minerals from the clast. The slope of the isochron determines the age (T) of the clast to be 4.07 ± 0.03 Gyr (AE).



was that the chemical composition of the finest grained material in the resulting synthetic regolith differed significantly from that of the coarsest. Compositional differences correlated with regolith grain size have long been observed in lunar soils, but their origins have remained controversial. According to one theory, fine-grained material is more easily transported over long distances by impact, and the observed compositional differences resulted because fine-grained material was added to local soil from mineralogically and chemically different terrains. According to another theory, these differences simply represented fractionation produced by mechanical differences in the ease with which different minerals are pulverized. Results of this experiment strongly support the second interpretation.

Origin of the Solar System

Cosmic dust and meteorites provide our best clues to processes which occurred during the birth of the solar system. Some of these samples are probably quite similar to the debris which accreted to form the planets. Many have remained relatively unchanged since the planets were formed 4.5 Gyr ago and, thus, provide a direct look at the sort of material from which planets formed. Some cosmic dust particles and certain clasts within very primitive meteorites may even represent condensates from the debris produced by stars which exploded before our solar system was formed.

The JSC is actively involved in the collection, curation, and study of both cosmic dust from the stratosphere and meteorites from Antarctica. Scientists at JSC have collected stratospheric dust samples using WB-57, U-2, and ER-2 aircraft equipped with inertial wing-mounted collectors. Last year, interplanetary dust particles in these samples were overwhelmed by volcanic debris from the eruption of the Mexican volcano El Chichón. This year, most of the volcanic debris appears to have settled out of the stratosphere, and the collection is again yielding significant numbers of particles of interplanetary origin. In addition to being stored, classified, and distributed to researchers by the JSC extraterrestrial materials curation group, these particles are intensively studied by JSC scientists. One significant finding in the past year is that many of the particles of a type called porous chondritic aggregates have been subjected to low-temperature chemical alteration. Particles of this type are believed to represent debris from comets intersecting the Earth's orbit. It was formerly believed that at the low ambient temperatures characteristic of most comets, little chemical alteration would occur. The new results suggest that such alteration occurs even at extremely low temperatures.

The Chemistry of Micrometeoroid Experiment (CME) was deployed on the Long-Duration Exposure Facility (LDEF) during the STS 41-C mission. Natural micrometeoroid collisions will be recorded on the collector surface of this experiment in the form of microscopic impact craters which contain molten impactor material on the bottoms and walls. The experiment will be returned from orbit in early 1985 after about 9 months of exposure. Laboratory chemical analysis of the residual material will provide information on the compositions of the impactor particles. The CME instrument collects both micrometeoroids and cometary dust and, thus, complements other cosmic dust investigations.

Primitive meteorites also provide information about the earliest history of the solar system. One particularly primitive type is called carbonaceous chondrites. The matrix of these meteorites consists of amorphous carbon and extremely fine-grained hydrous silicate minerals about which little is known. During the past year, JSC high-resolution transmission electron microscope studies succeeded in characterizing one of the matrix silicate minerals, which was formerly grouped with other matrix minerals as "poorly characterized phase." Only through laborious, meticulous work such as this will an understanding be gained of the origin of this primitive matrix material and of the alterations which it has undergone since formation.

In addition to matrix, primitive meteorites contain small spherical objects called chondrules. Chondrules have shapes and mineral textures indicating that they crystallized from molten silicate droplets. The means, the location, and the source material of melt droplet formation has been a topic of lively debate among meteorite researchers for decades. Results of experimental crystallization studies at JSC during the past year have given new insight into the thermal environment in which chondrules formed and into the nature of the precursor material. The experiment results indicate that observed mineral textures can be reproduced only if nuclei of the major minerals are present in the melt at the onset of cooling and crystallization. This result implies that the melts must be formed from crystalline starting material and, thus, rules out one popular theory of origin which calls for condensation of the droplets directly from a vapor. Moreover, the experiment results imply that the melts were not heated to such high temperatures that preexisting nuclei were destroyed.

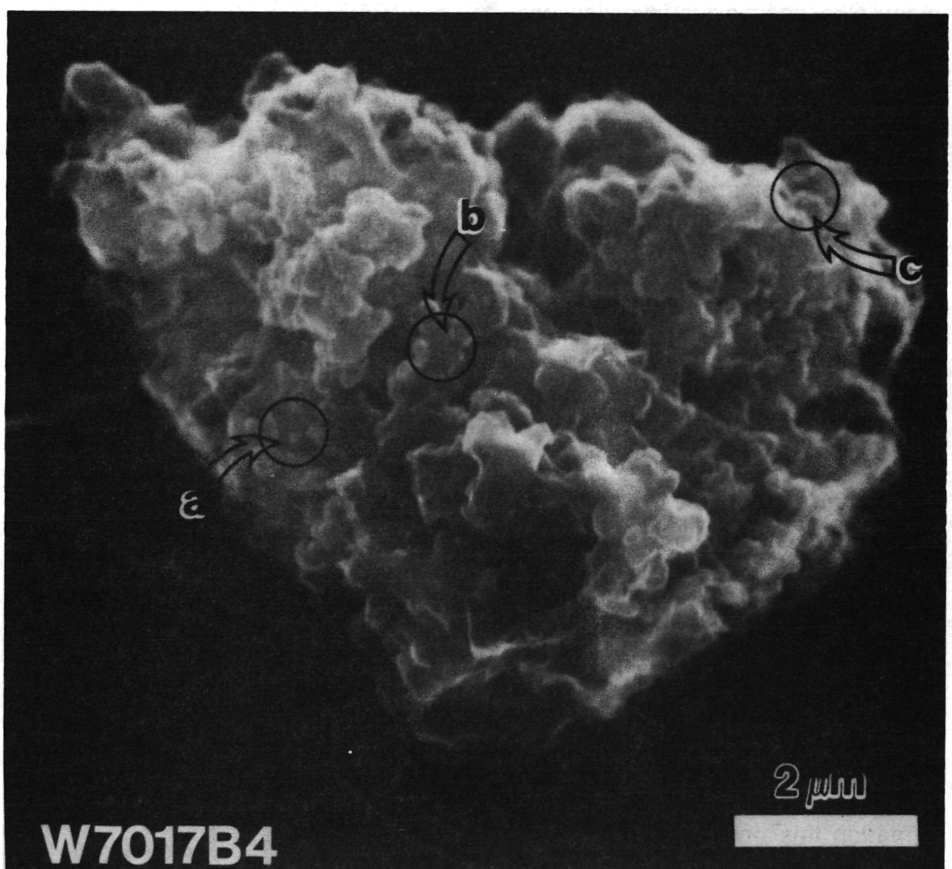
During the past year, JSC researchers and their academic colleagues continued to accumulate mounting evidence that four meteorites, including two from Antarctica, are samples of volcanic rocks from the surface of Mars. Strong similarities have been discovered between the rare gas patterns of these samples and those of the martian atmosphere as measured by the Viking lander. No other known material has similar patterns. Study of

A laboratory worker examining a cosmic dust flag in the class 100 clean laboratory. After completion of a sampling mission (normally, about 30 to 40 hr of total stratospheric exposure), the flag's particle content is sampled. The same laboratory is used both to prepare flags for flight and to process them after flight. All workers wear specially laundered, lint-free garments (head to toe) to minimize possibilities of contaminating the samples.

the cosmic-ray exposure ages of these and four related meteorites which also may be of martian origin indicates that initiation of exposure to cosmic rays occurred at four distinct times, which are much more recent than the 180-Myr age at which these samples were severely shocked. If the meteorites were ejected from Mars at the time of their measured shock age, then, to prevent cosmic-ray exposure, they must have been interior portions of relatively large objects (>6 m diameter). These large objects would then have undergone at least three space collisions in which they were fragmented to less than 1 m in diameter to initiate cosmic-ray exposure. Alternatively, the cosmic-ray ages might represent three separate impacts on Mars, each ejecting objects smaller than 1 m in size. In the latter case, the shock age would represent an earlier impact on Mars.

Confirmation by Japanese scientists of an additional lunar sample among the Antarctic meteorites, raising the total to three, suggests that ejection by impacts is not as rare as once believed. However, the mechanism by which material may be ejected from planetary surfaces during impact events remains highly controversial. Theoretical study of ejection mechanisms continues at JSC. Calculations suggest that large solid ejecta fragments, an appreciable fraction of the size of the impacting meteoroid, might be accelerated to velocities in excess of the martian escape velocity by aerodynamic drag forces in the impact vapor cloud.

A scanning electron microscope (SEM) image of a cosmic dust particle of a type called chondritic porous aggregate, collected from the stratosphere using NASA's WB-57F high-altitude aircraft. These extraterrestrial aggregates contain many thousands of extremely fine-grained particles (usually less than 1000 Å in size) with a variety of compositions (e.g., silicates, oxides, metals, and carbon). Scientists at JSC believe that some of these particles may be the remnants of an early solar nebula condensation event. However, recent work suggests that low-temperature alteration processes may have influenced the final composition of individual minerals.



Planetary Crusts

The early crust of the Moon, although not understood completely, can at least be sampled. Portions of the Earth's crust older than about 3 Gyr have largely been destroyed by erosion and geologic recycling processes and, hence, are not available for study. However, scientists at JSC are attempting to understand a somewhat later period in the Earth's evolution by studying 2.7-Gyr-old rocks from the Canadian shield, a tectonically stable region in northern Canada. These rocks consist of several chemical varieties of volcanic and intrusive melts within a single geographic area. The different chemical varieties would not normally be considered to be genetically related. One of the most significant findings of the past year is that a very precise radiometric dating technique has shown that the presumably unrelated rocks are of the same age, within the limits of resolution of about 1 Myr. Because normal crustal heating episodes are usually of longer duration, this synchronism imposes severe restrictions on the nature of the heat source for producing these melts. One heating mechanism which would satisfy the requirements is that the crustal plate in which the melts were formed passed over a hot blob of material upwelling from deep within the mantle. Such a mechanism is responsible for the volcanoes of the Hawaiian Islands. The new radiometric ages are the first evidence for the existence of such upwelling blobs, or "plumes," at such an early stage in the Earth's history.

Remote Sensing

Spectral reflectance is often used to study the nature of remote planetary surfaces. However, interpretation of remote-sensing data to infer mineralogical and chemical compositions of planetary surfaces requires understanding of the manner in which these compositions affect spectral properties of reflected light. As an aid to understanding spectral reflectance data from Mars, laboratory measurements are being made of spectral properties of potential martian soil minerals. Recent results indicate that both grain size and degree of disordering of iron phases have major effects on spectral properties. The degree of disorder among iron-bearing minerals, rather

than the specific kinds of minerals present, appears to be the most important parameter in producing the features observed in martian reflectance spectra. Thus, the new results suggest that martian spectra may place weaker constraints on soil mineralogy than is now generally believed.

Another ongoing JSC research program is related to the remote-sensing technique of radioastronomy. This program is an investigation of the fundamental physics of the generation of radiofrequency radiation by interaction of electron beams with plasma. Natural manifestations of this phenomenon include type III radio bursts from the Sun and interplanetary space, and decametric, hectometric, and kilometric bursts from Jupiter, Saturn, Uranus, and Earth. Better understanding of the fundamental physics of beam-plasma interaction will aid in interpretation of these radio signals.

Technology

To maintain capability as a leading research organization, an institution must continually develop, evaluate, and adopt new technology. The scientific staff of the Solar System Exploration Division continues to develop instruments and techniques to support its research programs and open future opportunities. Technical development within the past few years includes establishment of a clean laboratory and sample handling procedures for cosmic dust, continued development of a miniature automated isotope-dilution mass spectrometer and an associated wet-chemical processing laboratory for use on future comet or asteroid rendezvous missions, installation and operation of a state-of-the-art electron microprobe, development of analytical techniques to extend the sensitivity of electron microprobe analysis to lower levels than ever before, installation of Mossbauer analysis capabilities, installation of a calorimetry laboratory for measuring relative stabilities of different minerals as candidates for martian weathering products, development of a ceramic-electrolyte-controlled oxygen-reduction furnace for use as a future flight experiment, and development of capability for performing hypervelocity impact studies at liquid nitrogen temperatures.

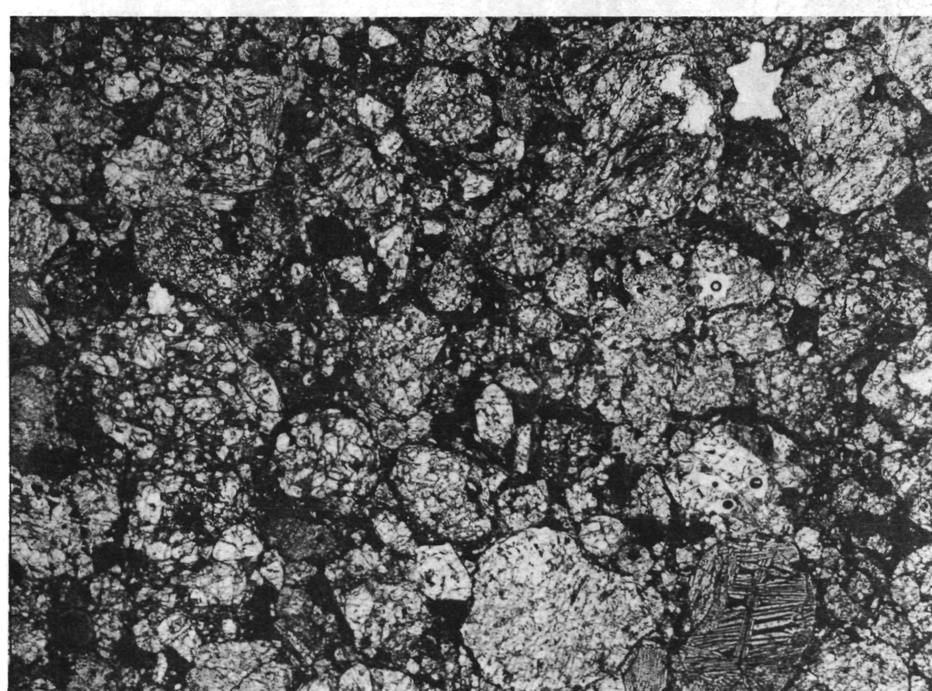
Technological research projects currently in progress include a study of effects of hypervelocity impacts on high-technology composite materials, the measurement of stratospheric ozone levels, an evaluation of the potential of electrodynamic tethered satellites for energy storage and orbit maintenance for Space Shuttle and Space Station operations, and an evaluation of sonic boom effects of Space Shuttle launch and landing operations.

Lunar Exploration

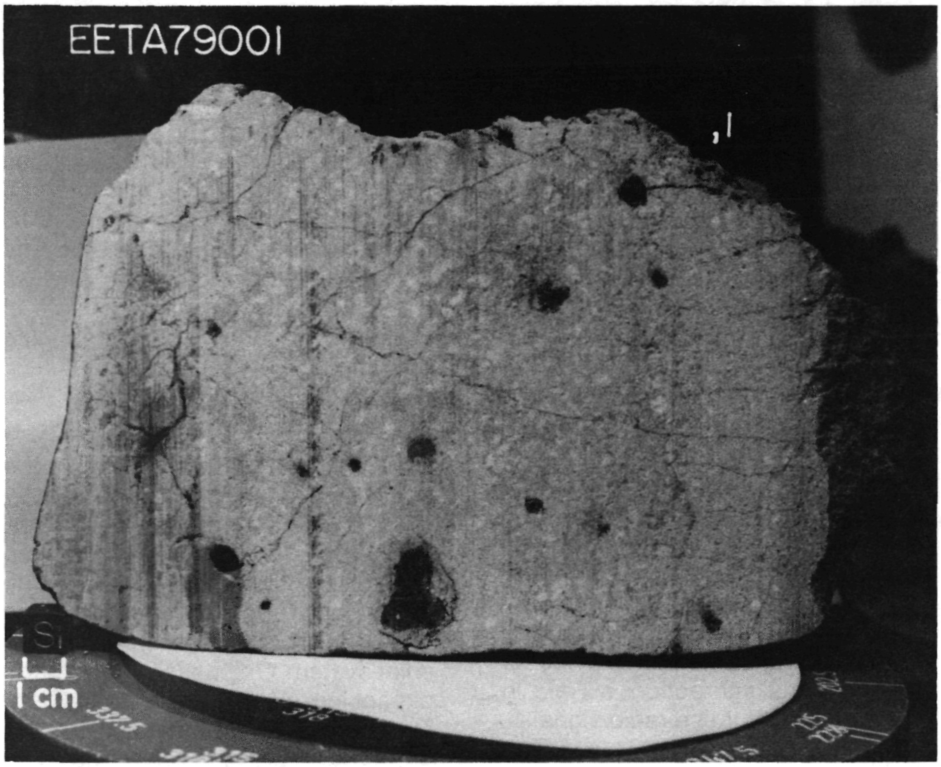
With the Space Shuttle now in the operational phase, the space agency is looking at future space activities. The Space Shuttle is but the first step in a process that can be viewed as an expansion of human activity into space — first near Earth, then farther into the solar system. One possible path such expansion might take is the establishment of a permanent base on the Moon. A permanently inhabited research base on the Moon could be in operation by the end of the first decade of the 21st century. Such a facility would enable intensive study of the Moon to address unanswered questions from the research of the Apollo era. It would also hasten the beneficial use of lunar materials for activities throughout the Earth-Moon system. Finally, it would prepare the way for manned exploration of Mars and the establishment of a second human society in the solar system.

Several key developments are necessary for the establishment of a lunar base. A space transportation system capable of delivering the base hardware and of resupplying the inhabitants is required. The uses of the lunar base must be made sufficiently clear to the leaders of society to ensure that investment in the enterprise will be supported. A project is being undertaken at Johnson Space Center to identify the principal objectives of a lunar base program, the current state of knowledge, and the developments necessary to implement the program.

A photomicrograph of a thin section of a chondritic meteorite. The field of view is about 2 mm long. The many round or oval objects are chondrules. They are composed of crystals of olivine and/or pyroxene, with interstitial melt. The regularly striped chondrule (lower right) is the clearest example of melt crystallization texture. The black areas between chondrules contain fine-grained matrix. In carbonaceous chondrites, this matrix consists of amorphous carbon and poorly characterized hydrous silicates. The chondrite shown is of a less primitive type, and the matrix consists primarily of finely crystallized olivine, metallic iron, and iron sulfide.



In the past year, three scenarios have been explored as possible models for the development of a lunar base. These scenarios involve using the base as a scientific outpost depending completely on external resupply in the manner of an Antarctic research camp, using it as a highly automated and eventually uninhabited mining and resource extraction facility, and using it as a laboratory for exploring the problems of developing extraterrestrial self-sufficiency. All three scenarios appear to require development of an enhanced space infrastructure, including orbital transfer vehicles, lunar landers, and space power systems. All scenarios would benefit from decreasing the cost of transportation from Earth to Earth orbit. Future work will include further definition of the activities to be performed at a lunar base, especially with a view toward utilization of lunar materials. Selected individual tasks are described in more detail in the reports which follow.



A sawn surface of a meteorite recovered from Antarctic ice which is believed to have originated as a volcanic rock on the martian surface. The small lighter gray areas are large crystals of olivine which grew from the lava. The large dark areas are pockets of impact-produced melt, possibly formed during the impact which ejected the sample from the surface of Mars. The dark veins are fractures filled with impact melt which thoroughly permeate the sample and connect the melt pockets.

Electrostatic mineral concentrator, used to concentrate the mineral ilmenite for use as feedstock in an oxygen production unit. Lunar soil is poured in the top and goes past successive electrodes which extract and concentrate ilmenite ($FeTiO_3$). The solar mirror heats the soil to enhance the separation.

Space Sciences and Applications

Solar System Exploration

Significant Tasks

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New Results for Some Old Rocks: Fra Mauro Revisited

PI: L. E. Nyquist/SN4
Reference OSSA 1

Examination of the Fra Mauro samples returned during the Apollo 14 lunar mission showed them to be impact-produced breccias. The radiometric ages of the breccias and of some lithic clasts within them are near 3.9 Gyr. The dominant component of most of the breccias is a rock type called KREEP because of its unusually high content of potassium (K), rare earth elements (REE), and phosphorus (P). Thus, it is widely accepted that this unusual rock type at the Fra Mauro site was excavated by the projectile which created the Imbrium Basin 3.9 Gyr ago during the "lunar cataclysm" of meteoroid bombardment.

Recent careful examination has shown that these samples contain fragments of previously unrecognized basalt types in the form of small lithic clasts. Moreover, radiometric age dating has shown that some of these basalts were formed before the lunar cataclysm and KREEP basalt volcanism. The oldest such basalt type so far identified is an olivine gabbronorite clast that is texturally and mineralogically similar to several Apollo 12 basalts. However, radiometric dating shows that the Apollo 14 basalt was formed 4.2 Gyr ago, about 1 Gyr earlier than the Apollo 12 basalts were formed.

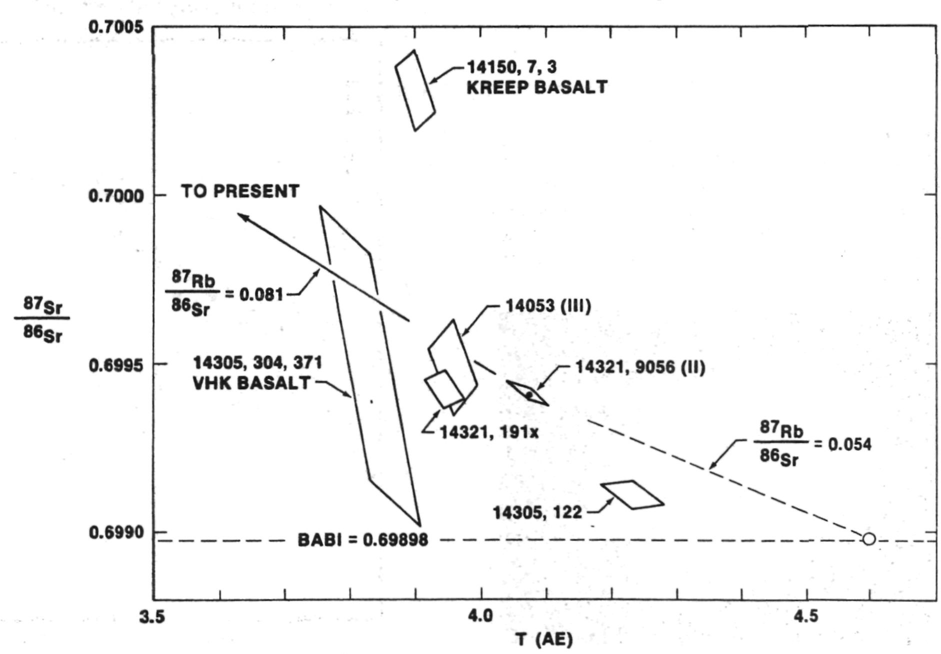
Some other basalts, rich in alumina and called aluminous mare basalts, also appear to have first formed before the onset of KREEP volcanism. A suite of five groups of such basalts has been identified among the clasts in the Apollo 14 breccia 14321. Type examples of groups for which radiometric ages do not now exist are being dated. An Rb-Sr isochron recently developed at JSC for one of the clasts from group II of the sample suite determines the age of the clast to be 4.07 ± 0.03 Gyr (AE), which is about 190 Myr older than KREEP basalts at the Apollo 14 site.

A third newly identified basalt type was found as a clast in Apollo 14 breccia 14305. This basalt type, called VHK basalt because it has a very high potassium content, has been dated as 3.83 ± 0.08 Gyr old, just slightly younger than the KREEP basalts at the site. The high potassium and rubidium content is a puzzle to lunar scientists, who are as yet unable to explain it as the result of normal igneous processes.

Ages of basalts found at the Apollo 14 site are summarized in a graph. Age (T) is plotted against the initial $^{87}Sr/^{86}Sr$ ratio which existed in the lava at the time that it solidified. The difference between the initial $^{87}Sr/^{86}Sr$ ratios of the basalts and the baseline value for the whole Moon when it formed (BABI) is proportional to the Rb/Sr ratio in the lunar mantle where the basaltic lava formed because of melting of mantle rocks. Such KREEP basalts as 14150,7,3 must have formed by melting of mantle rocks with significantly higher Rb/Sr ratios than the source rocks for the other basalts.

The occurrence of KREEP volcanism prior to mare basalt volcanism can be explained as being due to lower abundances of radioactive heat-producing elements, the abundances of which correlate positively with the rubidium abundance, in the mantle rocks which were melted to produce the mare basalts. However, it is difficult to explain why some basalts, such as 14305,122, which must have been produced by the melting of mantle rocks that were also poor in the heat-producing elements, were produced much earlier than KREEP basalts. The discovery of the old basaltic clasts in the Apollo 14 breccias thus poses a number of interesting new problems for lunar scientists, including the identification of areas in the lunar highlands at which mare-type volcanism may have occurred, and the reconsideration of the thermal evolution of the Moon.

A plot of the initial $^{87}Sr/^{86}Sr$ ratios of Apollo 14 basalts vs. their age, T.



Old Detrital Lunar Zircons

PI: Charles Meyer, Jr./SN2
Reference OSSA 2

The samples returned from the lunar highlands are almost all breccias. Many of these highland breccias contain a relatively high concentration of elements that are generally incompatible with the major rock-forming minerals (ilmenite, olivine, pyroxene, and plagioclase). These abundant elements include K, REE, P, zirconium (Zr), hafnium (Hf), uranium (U), and thorium (Th). Apparently, an early rock on the Moon contained high concentrations of these elements, yet few identifiable fragments have survived as clasts in lunar breccias.

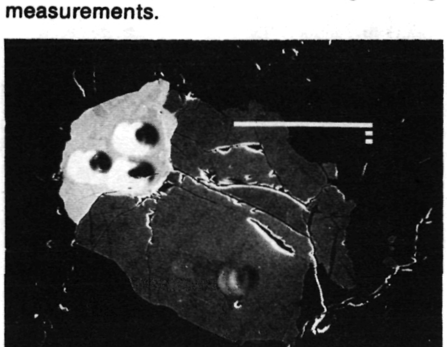
Zircon ($ZrSiO_4$) is a mineral that is known to be resistant to melting or dissolution. On the Earth, cores of zircons in granites are interpreted as detrital grains from the sediments from which the granites were derived. These zircons are often determined to be much older than the rocks in which they are found. Lunar zircons are only a minor, though important, phase in lunar samples and are difficult to find. Most mineralogical studies of lunar breccias have not previously reported zircons. Only when many thin sections are examined can enough zircons be located to make any sense of their presence. This year, relatively large zircons (greater than 100 μm) have been found in a number of trace-element-rich lunar breccias and melt rocks. These lunar zircons are as old as 4.4 Gyr and are much older than the breccias in which they are found. They are anhedral in shape and presumably represent the only residual phase of the hypothetical trace-element-rich rock.

Lunar zircons are important because they contain U and Th and can therefore be dated. The radioactive decay of U and Th to isotopes of lead (Pb) allows age interpretation from the precise measurement of the isotopes and the element ratios on very small spots (20 μm). Zircons from five lunar breccias have been dated. The illustration shows the U,Pb data from zircons from lunar breccia 73217. Two ages are determined from the data. The initial formation of the zircons was 4.356 Gyr ago, with a reheating event 1.680 Gyr ago. Similar results were obtained for the other four rocks, and, surprisingly, no evidence was found for the 3.9-Gyr lunar cataclysm which is thought to be the breccia-forming event.

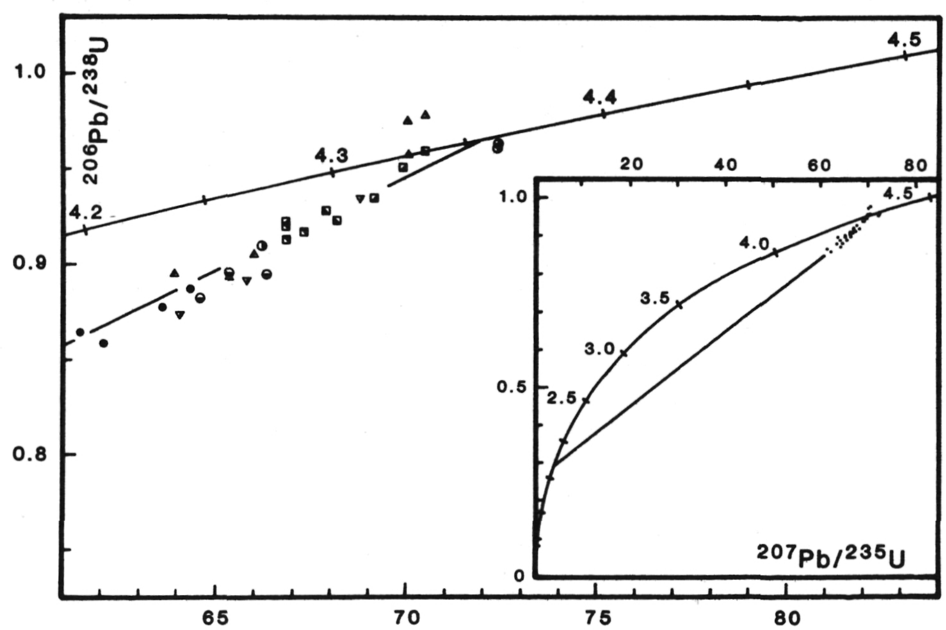
A few clues are available about the source rock for these lunar zircons. Analysis of the few mineral grains that are found attached to some of the zircons shows a wide range in the composition of plagioclase attached to zircon. This result seems to indicate that a variety of source rocks were involved. Another line of evidence is the clast assemblage in the same breccias. Lunar zircons are indeed found most often in breccias with a high percentage of "granite" clasts. It is believed that most of the other minerals in granite have dissolved in the breccia matrix, leaving the large anhedral zircon. Another possible line of evidence involves the chemistry of the zircons.

Old lunar zircons are important in that they could have formed only late in the differentiation sequence of the initially molten lunar surface. Their age of approximately 4.4 Gyr indicates that this process was complete within 100 Myr of the formation of the Moon, an indication that large planetary objects cool off much faster than theory predicts.

Photomicrograph of lunar breccia showing zircon (gray) with attached ilmenite (light gray), enclosed in silicate minerals (black). White bar is 100 μm long. Oval marks on zircon and ilmenite are pits etched in minerals by ion microprobe beam during dating measurements.



Uranium-lead isochron diagram for lunar zircons. If a sample has not been heated or shocked following crystallization, all data points will plot on the heavy "Concordia" curve, shown in the inset. The position of the data points along the curve will give the age of crystallization. If a sample has been reheated to cause lead loss, data points for different mineral grains will fall along a line which intersects the Concordia curve at the time of crystallization and at the time of reheating. Data for minerals which lost the least lead will fall closest to the old intersection, whereas data for minerals which lost nearly all their lead will fall near the young intersection. The zircons in this plot crystallized about 4.36 Gyr ago and were reheated about 1.7 Gyr ago.



Experimental Regolith Studies

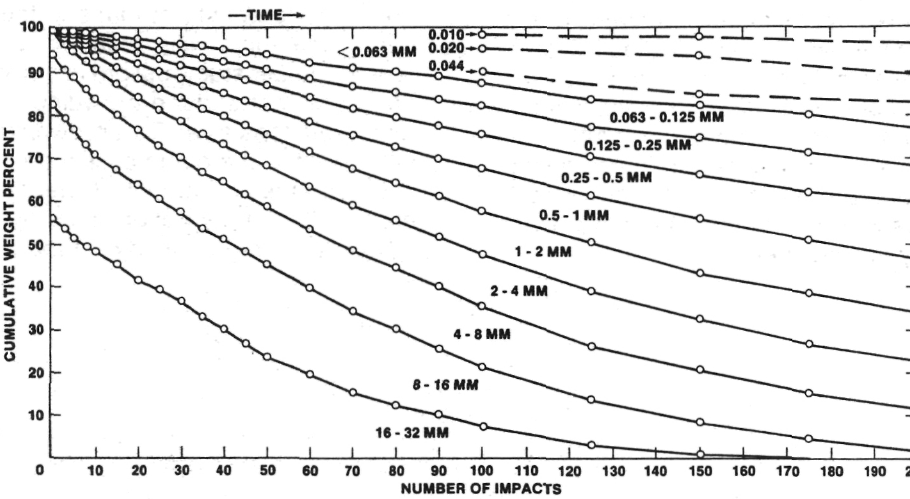
PI: F. Horz/SN4 and M. J. Cintala/SN3
Reference OSSA 3

Planetary surfaces are continuously pounded by meteorites throughout geological history. The presence and density or the absence of an atmosphere surrounding any particular planet largely controls the mass of a prospective impactor that may or may not reach the planet surface. Atmosphereless bodies such as the Moon and asteroids are continuously bombarded by relatively small meteorites that would, for example, not survive atmospheric entry on Earth. This small-scale impact regime causes disruption of surface blocks and boulders or gradually erodes solid bedrock. A fine-grained, fragmental layer termed regolith is generated; typical lunar regolith has median grain sizes of <100 μm. Total regolith thicknesses gradually build up over geologic time, and typical depths on the Moon are measured in meters. As a consequence, core samples of greater than 1 m returned during the Apollo missions may represent as much as a billion years of small-scale geologic history.

Some aspects of regolith evolution have been experimentally simulated by impacting the same initially coarse and blocky target 200 times. Stainless steel spheres were accelerated with a high-performance gun to a velocity of 1.35 km/sec. The illustration shows that the grain-size distributions evolve as a function of cumulative energy partitioned into the target. Note that the initial median diameter of 15.2 mm was reduced to 0.4 mm after 200 impacts. An average energy of 5×10^8 ergs/g of target mass was expended. It is estimated that lunar soils require energies in excess of 1×10^9 ergs/g. The comminution efficiency is nonlinear, an indication that comminution decreases with time because of a gradual change in the small-scale geologic environment. Initially, the projectile collides predominantly with large chunks and causes them to disrupt. At later stages, the target medium becomes sufficiently fine-grained for an actual impact crater to form. During cratering, fractions of the impactor's kinetic energy are consumed in target compression and ejecta displacement, and are therefore not available for comminution.

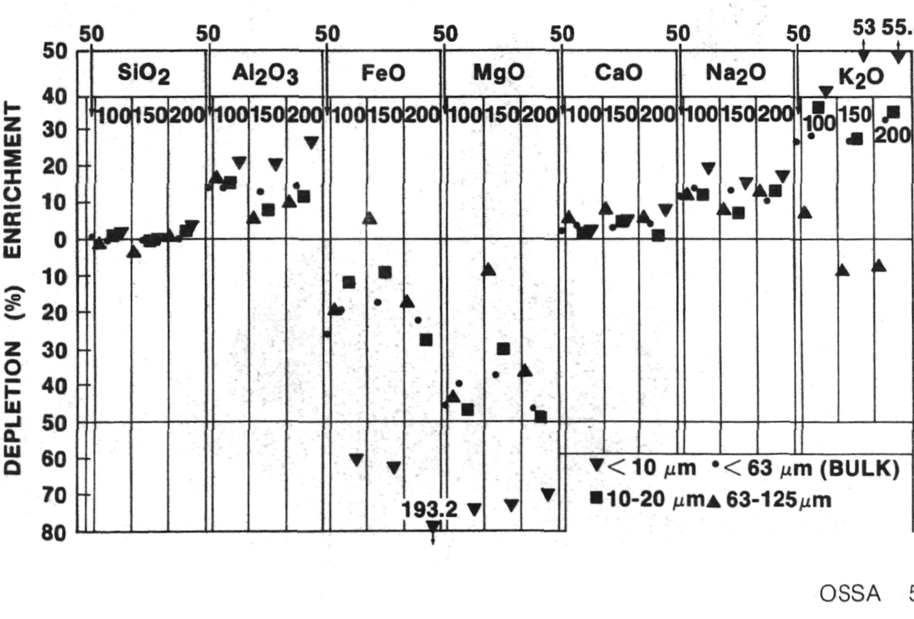
Aliquots of specific grain sizes were taken after certain numbers of shots for chemical analysis. The results are depicted as relative enrichment and depletion factors (%) with regard to the initial target rock, a gabbro, represented by the horizontal line through the 0% point.

The fragmentation products, especially the very fine-grained ones, differ in bulk chemistry from the initial starting material. They are enriched in oxides of aluminum (Al_2O_3), calcium (CaO), sodium (Na_2O), and potassium (K_2O) but are depleted in magnesium oxide (MgO) and iron oxide (FeO). The comminution products are differentiated: the feldspars are enriched; the pyroxenes, depleted. This finding is important because similar fractionation trends are observed in lunar soils. The common observation that lunar fines less than 10 μm in diameter differ in bulk composition from the average soil led many to theorize that this soil was ejecta from different lunar geological locations. The current experiments demonstrate that lunar chemical fractionation occurs during comminution of local bedrock.



Evolution of cumulative grain-size distribution as a function of total number of impact events in an experimental regolith.

Relative depletion and enrichment of specific oxides in various grain sizes after shots 50, 100, 150, and 200. The fine grain sizes are enriched in feldspar components (Al_2O_3, CaO, Na_2O, and K_2O) and depleted in pyroxene components (FeO and MgO).



The Antarctic Meteorite Collection

PI: John O. Annexstad/SN2
Reference OSSA 4

In 1969, a team of Japanese geologists made a chance discovery of meteorites near the Yamato Mountains, Antarctica. Field parties during the ensuing years have added more than 7000 fragments, more than doubling the world's collection. The Allan Hills sector, where U.S. teams have focused their search, has contributed nearly 2000 of these fragments to the treasure trove. Since 1978, JSC has assumed a lead role in the curation and distribution of these meteorites. To date, more than 2500 subsamples have been distributed to 139 investigator teams in 17 countries. Although the curatorial function is primarily one of characterization and distribution, basic research on the collection is also conducted. Data such as the location of the finds, ice movement, type distribution, weathering, and terrestrial ages are used to further the understanding of the concentration process by the ice sheet.

One ongoing project involves study of the movement of the ice sheet. The Allan Hills Ice Field was spanned in 1978 by a triangulation network designed to measure differential surface ice movement. The network was extended westward in 1982 and now covers more than 25 km west of the Allan Hills. Surface ice movement from west to east is very slow in this region and tends to decrease to zero as the Allan Hills are approached. Horizontal displacements greater than 1 m/yr are uncommon, with 20 to 30 cm/yr more prevalent at many locations. The rate of vertical emergence or submergence of the ice field gives some indication of being balanced by the rate of ablation. The known locations of the triangulation stations have been used to construct maps of the finds in the Allan Hills area. These maps are under study, but preliminary data show that surface crowding of meteorites does exist. This crowding is attributed to the compressive horizontal surface movement of the ice field and the concentration of smaller (10 to 100 g) fragments by katabatic winds.

Meteorite locations and ice movement measurements may have some relationship to the long terrestrial ages of these specimens. Theoretically, it has been predicted that the older specimens will be concentrated near the snout of the glacier or ice field. Although there is some indication of this effect, existing data are insufficient to prove the prediction. A complicating factor seems to be the nonuniform movement of the ice field in the region of highest specimen concentration.

Allan Hills meteorites do attain rather extensive terrestrial ages (approx. 0.2 to 0.3 Myr) but also exhibit an uncertain cutoff in age (approx. 0.5 Myr). The cutoff age may possibly be related to ice transport time and to the rate of the destructive process of weathering. If weathering is the main destructive process, the rate of destruction while the meteorite is encased within the ice vs. that while the meteorite is actually residing on the surface remains to be determined.

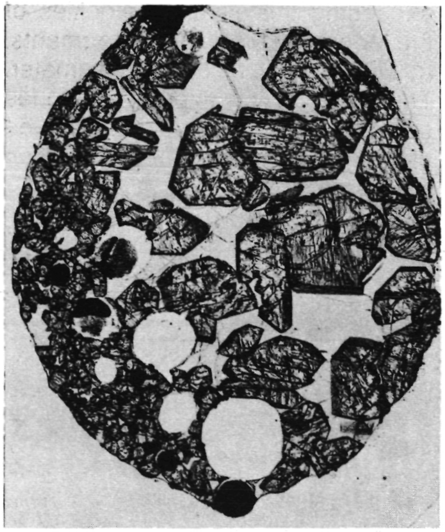
A snowmobile gives a height advantage in the search for meteorites.

Crystallization of Chondrules in Meteorites

PI: Gary Lofgren/SN4
Reference OSSA 5

Chondrules are small, generally spherical objects common in many meteorites. They have long been considered to contain important information about early solar system processes. Most chondrules with igneous textures are thought to be the result of rapid crystallization of nearly molten droplets. Recent experiments have supported this theory, but have raised questions about the details of the cooling process and have not answered the basic question about the origin of chondrules. The textures in chondrules have been reproduced in dynamic crystallization experiments, but at cooling rates slower than those predicted by the cooling of molten spheres in space. Obviously, additional factors are important; either the cooling must be slowed by some formation process or the textures must be produced at cooling rates higher than those already determined experimentally.

Photomicrograph (25×) of experimentally produced porphyritic chondrule texture with large euhedral, near-equant pyroxene phenocrysts (cooled at 5° C/hr).



Dynamic crystallization experiments have been performed on a synthetic material that simulates the composition of porphyritic pyroxene chondrules. Variations in texture were studied as a function of heterogeneous nucleation and cooling rate. Preliminary products encompass a wide range of textures including radial, porphyritic, and granular pyroxene, porphyritic olivine and pyroxene, and barred olivine or pyroxene.

The liquidus temperature was determined to be 1505° ± 5° C with pyroxene as the liquidus phase. The samples were melted at temperatures above and below this value for 17 hr. As illustrated, subliquidus melts produce granular, equant-euhedral, and skeletal pyroxene porphyritic textures when cooled. An exception is very fast cooling rates (about 2500° C/hr), where radial pyroxene encloses sparse phenocrysts. The transition between granular and equant-euhedral porphyritic textures occurs with melt temperatures approximately 30° to 50° C below the liquidus, with the lower melt temperatures producing granular textures. The equant-euhedral phenocrysts grow in runs with melt temperatures 10° to 25° C below the liquidus. Melt temperatures slightly above this range produce the illustrated porphyritic and barred texture with skeletal phenocrysts and 10% to 30% glass. In all subliquidus melt runs, olivine is present only as inclusions in the pyroxene.

With melt temperatures above the liquidus, olivine is the dominant phase crystallized. Porphyritic and barred olivine textures have been produced along with more chaotic dendrite textures. The transition from porphyritic pyroxene to porphyritic olivine occurs at melt temperatures near the liquidus. At higher melt temperatures, there is a transition to barred olivine or parallel dendrites.

The main conclusion is that the temperature history of the melt as it affects the nucleation process controls the texture. The higher melt temperatures reduce the variety and density (number per unit volume) of heterogeneous nuclei. The presence of fewer nuclei in the melt leads to the production of fewer but larger crystals. This effect is seen in the transition from granular to equant porphyritic pyroxene texture. The importance of heterogeneous nuclei to the crystallization of the broad variety of observed textures suggests that a crystalline precursor is important in the chondrule-forming process.

Photomicrograph (25×) of experimentally produced barred pyroxene texture with elongated, skeletal pyroxene crystals (cooled at 100° C/hr).

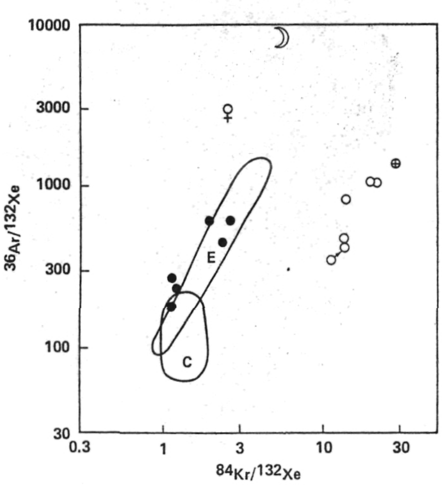
Trace Gases in SNC Meteorites and Implications for a Martian Origin

PI: Donald Bogard/SN4 and Larry Nyquist/SN4
Reference OSSA 6

Isotopic concentrations of the noble gas elements have been measured in three meteorites belonging to the rare group of SNC achondrites for which a variety of mineralogical, chemical, isotopic, and chronological data suggest an origin from the planet Mars. As illustrated, shocked phases of one sample contain a trapped argon (Ar), krypton (Kr), and xenon (Xe) component having elemental and isotopic ratios unlike those for any other noble gas component except the martian atmosphere as analyzed by Viking spacecraft. It is hypothesized that these gases represent a portion of the martian atmosphere which was shock-implanted into this sample during a large impact event, and that they constitute direct evidence of a martian origin for the SNC meteorites. The time of shock emplacement of this trapped gas is most likely given by the 180-Myr age determined by the Rb-Sr isochron dating technique for the mineralogically defined subgroup of four of these meteorites, the shergottites.

Cosmic-ray-produced gases in the eight known SNC meteorites form three distinct groups with cosmic-ray exposure ages of ~11, ~2.6, and ~0.5 Myr. These ages suggest three distinct breakup events and cannot have been produced by particle irradiation for a common time under greatly different shielding in objects of different sizes. Comparison of cosmogenic helium-3/neon-21 ($^{3}He/^{21}Ne$) ratios measured in one meteorite with two independent models for the production of this ratio as a function of shielding indicates that this meteorite was irradiated in space as a relatively small object. If the SNC meteorites were ejected from Mars ~180 Myr ago, the measured shock age of the shergottite subgroup, they must have been relatively large objects (>6 m diameter) which experienced at least three space collisions to initiate cosmic-ray exposure. The table shows that ejection from Mars by three events at the times of initiation of cosmic-ray exposure would permit the ejected objects to have been much smaller (<1 m diameter), but would require three such events on 1.3-Gyr martian terrain in the past ~10 Myr and would not explain the common 180-Myr shock age seen in all four shergottites. The three scenarios for the cosmic-ray irradiation history of SNC meteorites in the table are as follows. In scenario I, it is assumed that all SNC's were ejected in a common event from their parent planet 180 Myr ago and underwent multiple breakup events in space. Scenario II is based on the assumption that three different events ejected the SNC's from their parent planet at the time of initiation of cosmic-ray exposure. In scenario III, it is assumed that seven of the eight SNC's were preirradiated on their parent planet before ejection in a single event ~0.5 Myr ago.

The mechanism by which meteorites may be ejected from planetary-sized bodies such as the Moon and Mars remains controversial. We suggested that solid ejecta fragments might be caught up in the rebounding vapor cloud produced by a grazing impact of a large meteoroid with the martian surface and accelerated by aerodynamic drag forces to velocities approaching that of the vapor cloud. A simplified calculation shows that objects which are an appreciable fraction of the size of the impacting meteoroid might be accelerated to velocities in excess of the martian escape velocity in this manner. This calculation ignores the possibility that solid fragments entrained in the vapor cloud might be crushed by the pressures exerted on them, an assumption which has been questioned by others. However, it has been pointed out that suitable grazing impact source craters for both SNC and lunar meteorites exist on Mars and the Moon. Moreover, the expected relative yield of meteorites from such grazing impacts is comparable to the relative proportions of SNC and lunar meteorites. Sophisticated computer simulations of grazing impacts are now under way by other investigators. One of these alternate ejection mechanism theories is that small near-surface fragments produced near "ground zero" of an impact could be accelerated to velocities exceeding the escape velocities of the Moon and Mars. Such fragments, however, would be ≤1 m in diameter. Thus, the possible exposure histories summarized in the table constrain the nature as well as the timing of martian ejection events.



A plot of $^{36}Ar/^{132}Xe$ versus $^{84}Kr/^{132}Xe$ isotopic ratios for various solar system materials. Values for the Earth's atmosphere, Mars' atmosphere, Venus' atmosphere, and solar wind gases trapped in ilmenite grains of the lunar regolith are shown as the respective planetary symbols. Data for trapped gases in various classes of meteorites fall in the fields labeled C and E and are shown as filled symbols. Data for trapped gases in five samples of one of the SNC meteorites are shown as open circles lying between the data for the Earth and Mars. These gases are consistent with a mixture of martian and terrestrial atmosphere, but are inconsistent with all other known solar system components.

Characteristic	Scenario		
	I	II	III
Time of Mars ejection events, Myr	180	11, 2.6, 0.5	0.5
Number in 1.3-Gyr-old rock	1	3	1
Number in 180-Myr shocked rock	1	2	1
Required ejected fragment size, m	>6	≤1	>6 and <1
Required space collisions to initiate cosmic-ray exposure, Myr	11, 2.6, 0.5	None	None

Chronology of Ancient Terrestrial Igneous Events

PI: William C. Phinney/SN4 and Don Morrison/SN4
Reference OSSA 7

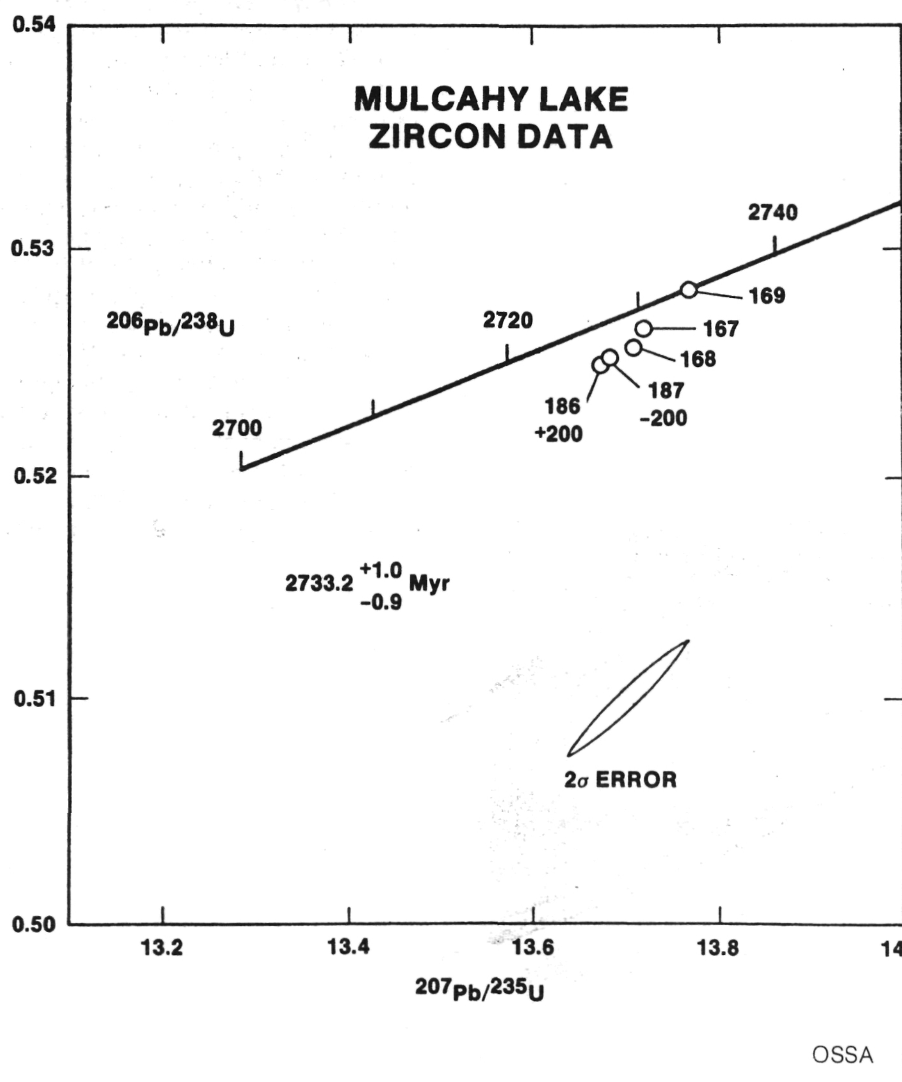
A significant fraction of the Earth's crust was formed in Archean times (ca. 3.8 to 2.5 Gyr ago) by processes not yet fully understood. No Proto-Archean rocks have been identified, although there are hints that such rocks exist. Archean terrains occur on every continent and consist primarily of volcanics (greenstones) and silica-rich intrusives (granitics). The granitics typically encompass thousands of kilometers and deform and obscure earlier formed greenstones and associated mafic (Mg and Fe rich) rocks. Reconstruction of these crustal-forming events depends on time measurements, generally through analysis of radioactive isotopes, because of the absence of fossils. Broad-brush chronological frameworks have been constructed for most Archean terrains, primarily on the basis of Rb and Sr, with some recent results from the samarium (Sm) and neodymium (Nd) system. Data from these systems indicate timespans of tens to several hundred million years for development of typical greenstone-granite sequences, each representing new additions to the crust. Commonly, the ages are ambiguous, particularly in the Rb-Sr system, because of alteration and metamorphism. Consequently, models of crust-forming processes tend to be excessively generalized.

This longstanding problem is being attacked by new sample preparation and analytical techniques for uranium and thorium isotopes in zircons. The new techniques, developed by Canadian researchers, have reduced the error in zircon age measurements by an order of magnitude, and by two orders of magnitude over the results typical for Rb-Sr or Sm-Nd measurements. These techniques have been applied to samples collected from mafic intrusives, associated volcanics, and intrusive granitics from the Archean terrain of western Ontario. The Rb-Sr and Sm-Nd data cannot resolve the timespan of formation of these rocks to better than about 50 Myr. In contrast, zircons extracted from one of the mafic plutons yield an age of 2733.2 +1.0/-0.9 Myr, the most precise age ever measured on a rock of its type, and zircons from the granitic rocks which intrude the mafic unit yield ages of 2732 ± 2 Myr.

These precise zircon ages show that both mafic plutons and granitic rocks were generated during the waning stages of mafic volcanism. The extremely short interval between formation of mafic and granitic rocks restricts models of crustal development significantly. A plausible mechanism which is observed to occur in the present is the passage of a mantle plume. Passage in this case implies the movement of crustal plates over a plume rising from the mantle, carrying with it heat, which produces igneous activity. Whatever the mechanism, the very precise zircon ages show that the pace of events in Archean time in western Ontario was sufficiently rapid that major crustal-forming events and processes are not resolved by Rb-Sr and Sm-Nd age measurements.

An interesting aside in this work has been a reexamination of decay constants for rubidium and samarium. The half-life of rubidium was determined in 1956 to be 5 Gyr, equivalent to a decay constant of 0.0139/Gyr. Later work suggested a half-life of 4.88 Gyr and a decay constant of 0.0142/Gyr. The latter figure is commonly used, although several laboratories including the Johnson Space Center use the older number. The Rb and Sr isotopic data from the rocks precisely dated by the zircon technique strongly suggest that the older decay constant and half-life are the correct values. No change is indicated in the Sm decay constant.

Uranium-lead isochron for Canadian zircons. Intersection of data point trend with heavy "Concordia" line gives formation age of zircons as 2.733 Gyr.

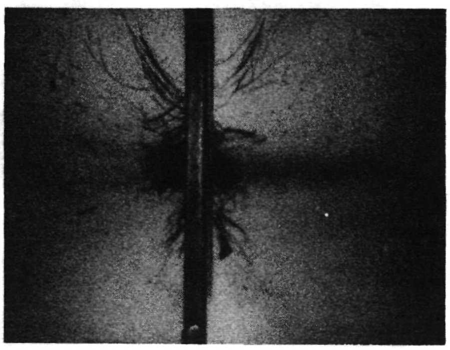


Hypervelocity Impact Studies of Composite Materials

PI: Jeanne Lee Crews/SN3
Reference OSSA 8

Commercially available composite materials such as graphite/aluminum, boron/epoxy, graphite/epoxy, and Kevlar/epoxy are being employed in aerospace applications on a steadily increasing scale. These materials and other composites under development are being used to replace aluminum and magnesium for certain types of structures because of their unique physical properties (i.e., high stiffness coupled with low thermal deformation) and directional strength properties tailorable to the application.

The ejecta/spallation from an impacted ¾-in-thick plate of graphite/epoxy. The model (projectile) flight is from right to left. The model was a ¼-in-diameter aluminum sphere. Impact velocity was 19 600 ft/sec.



When used for the primary surfaces of long-duration space structures, composite materials will be exposed to meteoroid and space debris impacts at average relative speeds between 10 and 20 km/sec. Therefore, JSC has undertaken a test program (1) to characterize the damage inflicted to a composite plate from impact and penetration by a foreign object of known properties traveling at hypervelocity; (2) to develop an empirical damage relationship between the characteristics of the composite material (thickness, layup, directional properties, epoxy content, etc.) and the impact parameters (projectile size, shape, density, mass, and velocity); (3) to identify the debris generation potential and the ejecta particle size distribution of composite materials; and (4) to perform empirical testing of composites in comparison to similar testing on metals to provide near-term data for composite acceptability.

To investigate the resistance of composite materials to hypervelocity impacts, a small light gas gun built at JSC and a large light gas gun at the Ames Research Center (ARC) are used. The small light gas gun can fire small (<5 mg) projectiles at velocities ranging from 3.5 to 8 km/sec. The large light gas gun can fire larger (>1 g) projectiles at velocities of 7 km/sec. Samples of graphite/epoxy, manufactured to industrial specifications and representing the state-of-the-art fiber, resin, and layup technology, are impacted and sent to the University of Texas for analysis. To date, 450 shots have been made with the JSC gun, a large percentage of which were for the calibration of the gun. Two test series have been performed using graphite/epoxy samples impacted at velocities ranging from 3.8 to 6.95 km/sec.

Damage analysis consisted of measurements of the crater and delamination and the study of the spread of internal damage by means of edge replication, die penetrant, sectioning, and microscopic examination. The results of analysis of the first series of samples showed that, unlike metals, composite materials do not exhibit a clearly defined damage pattern under impact loadings. The damage to graphite/epoxy consists of surface peeling, tunneling, plugging, fractured or melted laminae, delamination, and an ill-defined crater. The extent and degree of internal damage to the matrix has proved difficult to ascertain without the use of an ultrasonic scanning device. Such a device has been purchased and will be used on the next series of test samples. The examinations of the samples using the C-scan will record any special characteristics of the damage and quantify whenever possible the results of the scanning process by identifying the extent of major structural degradation such as delamination and severe matrix damage.

In addition to the two test series performed using the JSC gun, several larger and thicker samples were impacted using the larger ARC gun. The ARC series consisted of varying the temperature of the samples, the angle of impact, and the size and material of the impacting projectile. These samples will be used to extrapolate the damage assessment as a function of projectile size and mass between the small projectiles using the JSC gun and the large projectiles using the ARC gun.

It is anticipated that the use of the C-scan will aid in quantifying the damage inflicted to a composite plate when impacted by a hypervelocity projectile. The study to determine the debris generation potential and the ejecta particle size distribution of composite materials will be initiated in the near future.

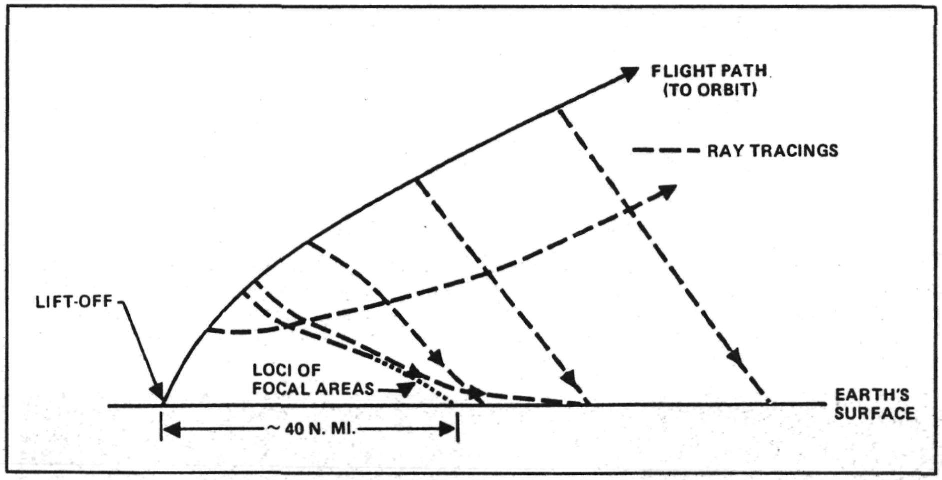
Sonic Boom Studies

TM: John Stanley/SN3
Reference OSSA 9

Space Shuttle environmental effects have been a major consideration since the conception of the program. One of the areas monitored has been sonic boom effects. Although the sonic boom associated with supersonic aircraft has been studied in depth and is relatively well understood, the Space Shuttle vehicle differs significantly from these aircraft in both geometric and operational characteristics, particularly during launch. The need for an experimental data base to verify or modify existing theories with respect to these differences is well recognized.

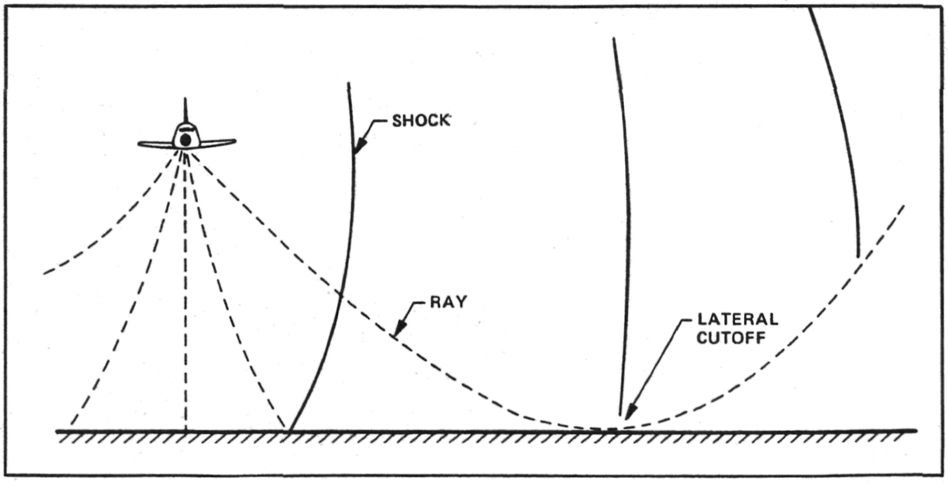
During the past 12 months, the Johnson Space Center has conducted sonic boom measurements during the descent and landing of the STS 41-B Orbiter and the ascent of the STS 41-D vehicle. Eight sonic boom measurement sites were deployed across the State of Florida for the STS 41-B descent. The sonic boom levels measured varied from 0.5 lb/ft^2 on the west Florida coast to a maximum of 1.8 lb/ft^2 at Mims, Florida, on the east coast. The maximum predicted overpressure was 2.2 lb/ft^2 a few miles west of Mims. The measured values are consistent with model predictions and previous measurements made during the STS-1, STS-2, and STS-4 landings in California. The measured values should be representative of levels produced by future landings following nominal entry trajectories.

As illustrated, a strong focusing of the sonic boom occurs during ascent because of the pitchover and acceleration of the Space Shuttle trajectory. In simple terms, this phenomenon occurs when the pressure wave originating from different points on the trajectory reach the ground at the same place and time. During the ascent of the STS 41-D vehicle, several important parameters were measured. First, the leakage of the pressure wave in front of the focus line was found to be much greater than previous measurements (STS-7) had indicated. These data were obtained from several boats that were west of the focus line. The magnitude of overpressures ranged from 0.37 to 3.2 lb/ft^2. Also, the illustration shows that the lateral cutoff, the region in which the shock waves are refracted upward by the atmosphere, was measured and found to be consistent with model predictions about 40 n. mi. from the groundtrack of the Space Shuttle. Here again, though, considerable diffusion of the pressure wave seems to be occurring; the effect in the lateral cutoff region was to extend the pressure wave outward an additional 10 to 12 n. mi. This diffusion of energy in both the focus region and at lateral cutoff is probably the result of a nonhomogeneous atmosphere.



Shock wave propagation paths for shocks originating from various points along the flight.

Atmospheric refraction of the propagation paths showing the lateral cutoff.



Lunar Base Planning Studies

TM: M. B. Duke/SN
Reference OSSA 10

In work done at the Johnson Space Center this year, three scenarios have been explored as possible models for the development of a lunar base. The first of these scenarios consists of a base which would serve as a scientific research outpost, similar to an Antarctic research camp, where exploratory excursions could be outfitted and supplied, where supporting shops and laboratories would be available, and where scientific observation equipment could be set up and operated. This base could be temporarily or, eventually, permanently inhabited but would depend largely or completely on resupply from Earth.

The second scenario consists of a mining and resource extraction facility which produces material for export, such as liquid oxygen used as rocket propellant by the Space Transportation System. This facility would be highly automated and possibly only temporarily inhabited following initial setup and checkout.

The third scenario consists of a base which is established principally to explore the problems of developing extraterrestrial self-sufficiency. This base would start with modules and equipment brought from Earth but would develop the capability to use lunar materials to expand habitable volumes, power generation, and resource extraction, and would begin to build a closed ecological life support system, including lunar agriculture, which would supply most of the needs of the base population.

Early analysis of these scenarios demonstrates that they require the development of common portions of a space infrastructure. Starting with a station in low Earth orbit, orbital transfer vehicles capable of transporting on the order of 20 tons to lunar orbit will be required. In early stages of the program, expendable lunar landers will be used to deliver cargo to the lunar surface and expendable launchers to return people to lunar orbit. Later, a reusable vehicle for transportation from lunar orbit to lunar surface and return will be required. Lunar bases will require substantially larger amounts of power than currently envisioned for space stations, in the megawatt range. This increased power need will require the further development of space power systems, either nuclear or solar-based. All scenarios benefit from decreasing the cost of transportation from Earth to Earth orbit, possibly through an unmanned cargo-carrying version of the Space Shuttle.

The fully developed space infrastructure needed to support a lunar base program will serve various other uses in space, including the potential to place large payloads in geosynchronous orbit or to launch a spacecraft for the human exploration of Mars. In the next year, further definition of activities that would be performed at a lunar base will be undertaken, particularly in the area of utilization of lunar materials to support lunar domestic activities.

Artist's conception of a lunar outpost in the low-latitude region of the Moon. A solar furnace testbed is in the foreground. A habitat module (left) is buried under lunar soil to protect the human inhabitants from the effects of cosmic rays. A mining operation takes place in the upper right portion of the drawing. The solar furnace processes raw lunar regolith to produce liquid oxygen for rocket fuel.

Space Sciences and Applications

Life Sciences

Summary

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Office of Space Sciences and Applications

Life Sciences

Summary

Four Space Shuttle flights were completed in fiscal year 1984. During the period, the focus of life sciences activities has continued to be on streamlining medical operations for the routine operational Space Shuttle phase projected to include many more flights per year. In addition, conceptual development of plans for the medical aspects of a Space Station has undergone growing in-house study. The Johnson Space Center (JSC) continues to conduct a broad range of medical research projects in support of the following Life Sciences Program goals.

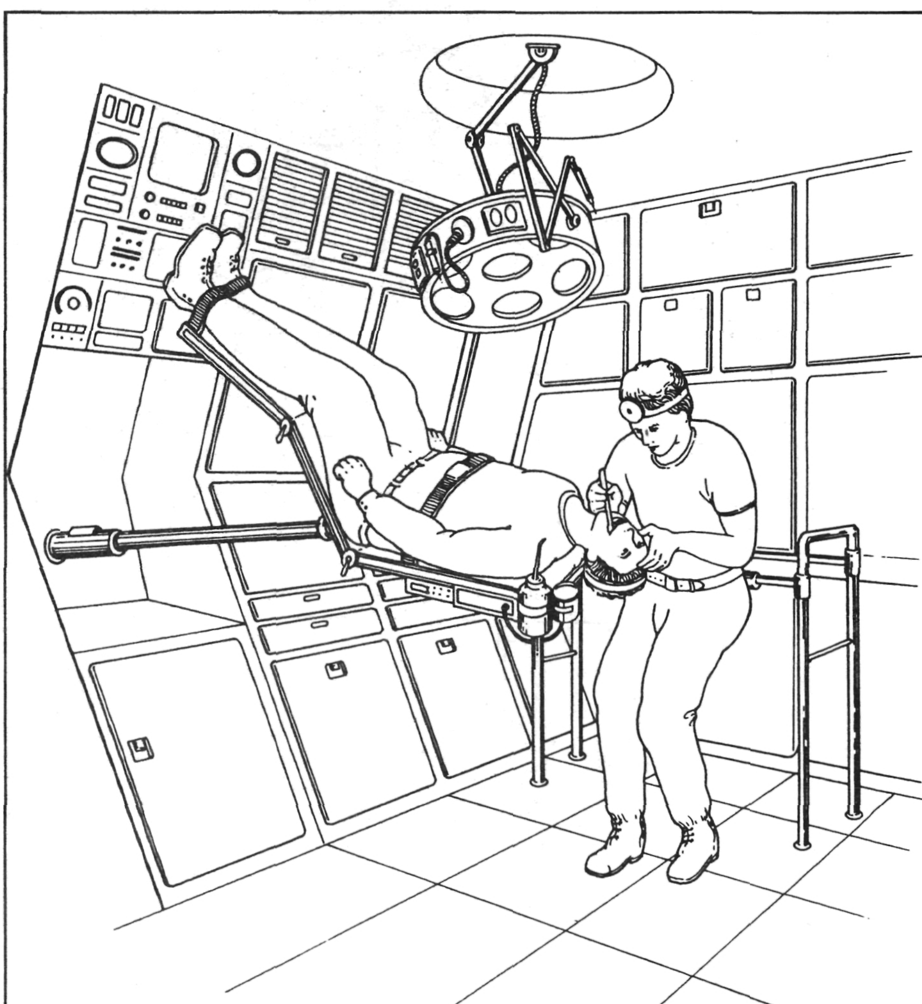
1. To ensure the long-term health, well-being, and performance of humans in space, to characterize the medical constraints of space flight, and to facilitate participation by a broad segment of the population
2. To use the space environment as a means of increasing fundamental knowledge in medicine and biology
3. To conduct the research and technology development necessary for maintaining life in space on a self-sustaining basis for long periods

The Medical Sciences Space Station Working Group, established in June 1982, continued to explore "Medical Operations and Life Sciences Activities on Space Station"; NASA Technical Memorandum 58248 with that title was published in October 1982. In February 1984, the Working Group published NASA Technical Memorandum 58255 entitled "Space Station Medical Sciences Concepts," in which 13 medical sciences areas are discussed and illustrated by conceptual sketches, examples of which are shown. In May and again in July 1984, the Space Station ideas were put forth first at the Aerospace Medical Association meeting and second at the Intersociety Conference on Environmental Systems of the Society of Automotive Engineers, both held in San Diego. Planning activities have continued.

In-house efforts have helped identify changes in physiology occurring when a human is no longer under the effects of gravitational force. Important among these effects are the following.

1. Otolith organs send out uncharacteristic signals to which the nervous system must adapt.
2. Proprioceptive input greatly diminishes.
3. Muscles of locomotion and posture begin to atrophy.
4. Portions of the skeleton needed for ambulation and standing lose bone mineral.
5. The increased availability of bone and muscle constituents requires renal, gastrointestinal, and hematological adjustments.
6. Labile portions of the extracellular fluid are excreted as they are no

Dental health can be monitored during flight in the medical facility.



longer needed.

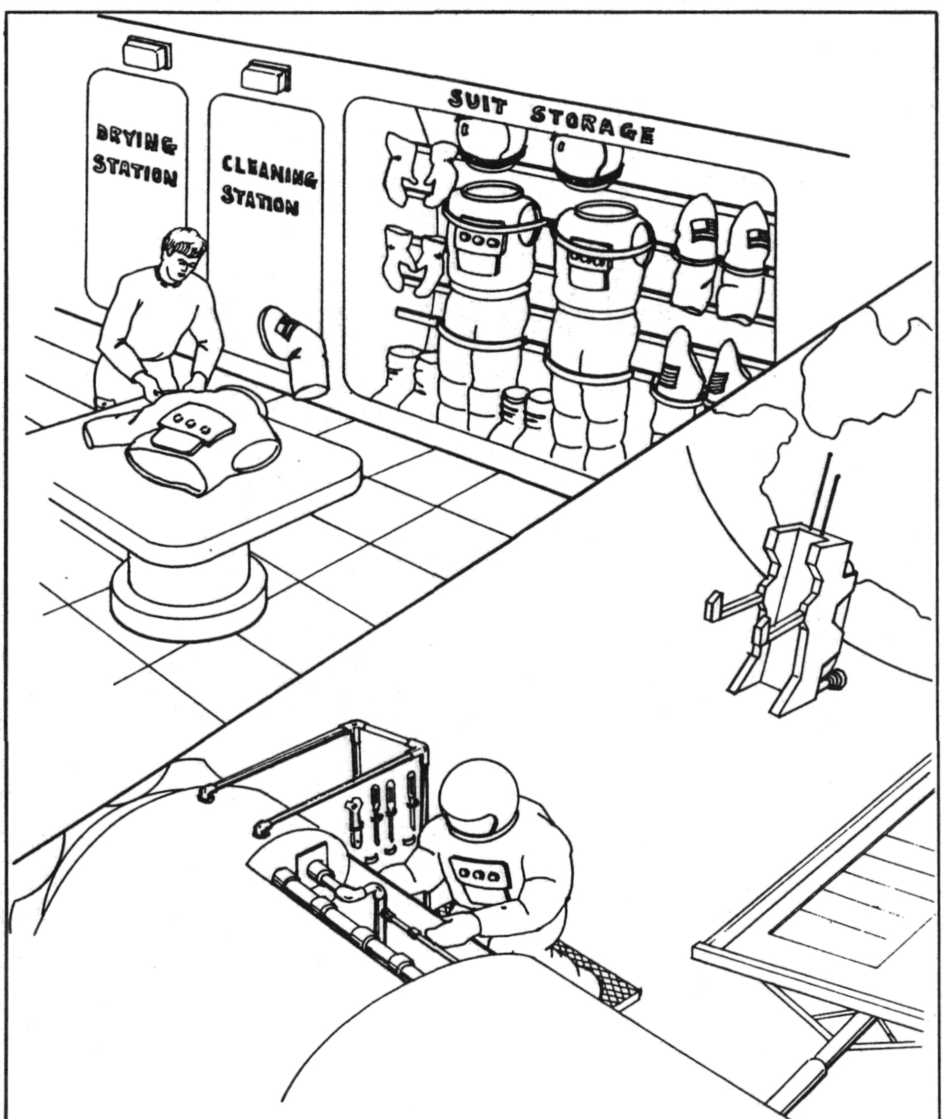
7. Fluid adjustments tend to unload the heart and, thereby, to decrease its end diastolic volume and to cause cardiac muscle changes.

1984 Physiological Investigations

Since the onset of manned space flight, NASA has been a leader in the study of motion sickness. It is theorized that understanding neural adaptations to changing gravitational directions will lead to a better understanding of motion sickness both on Earth and in orbital flight. An increased emphasis and effort to understand the causes of and to prescribe therapies for motion sickness has been made possible by the establishment of the NASA Space Biomedical Research Institute (SBRI), which is supported by the Universities Space Research Association (USRA) Division of Space Biomedicine. An early SBRI study report has examined the central-nervous-system-mediated physiologic adaptations through operational biobehavioral training. The USRA's Division of Space Biomedicine will continue to work in concert with JSC in determining the causes of and the cures for space motion sickness.

Another effort under the SBRI is to use the parallel swing tests. The test employs a four-pole pendulum that produces "linear" and/or angular (roll) oscillation. Three types of responses are examined: linear self-motion detection thresholds, perceived self-motion path, and eye movements. The data are relevant for the hypothesis that changes in established otolith responses contribute to the symptoms of space adaptation. Other space-motion-sickness studies have been undertaken. These include rotating devices which permit precisely controlled angular acceleration stimuli. The JSC is developing a rotator for use on the Space Shuttle Orbiter middeck. Another effort is the screening of drugs such as sublingual scopolamine as a countermeasure for the prevention or curtailment of space motion sickness. The current focus is on a tablet that would dissolve against the cheek.

Portable work stations onboard the Space Station provide essential equipment for the care and maintenance of pressure suits.



Also investigated is the use of an echocardiography technique to better understand and quantitate the physiologic alterations produced in the heart during space flight. Work has begun to examine altitude decompression sickness, caused by the formation of nitrogen bubbles in the body following changes in pressure from the Orbiter's normal cabin pressure (14.7 psi) to that of the Space Transportation System (STS) extravehicular suit (4.3 psi). During 1984, extensive manned chamber tests were conducted to examine repetitive extravehicular activities (EVA's) within a 3-day period.

Work is continuing on the examination of the mechanisms involved in physiological changes demonstrated in bone, muscle, and blood after exposures of humans and animals to microgravity. Work is being done to determine effective countermeasures. Magnetic resonance imaging (MRI) or nuclear magnetic resonance (NMR) devices will be used in this work.

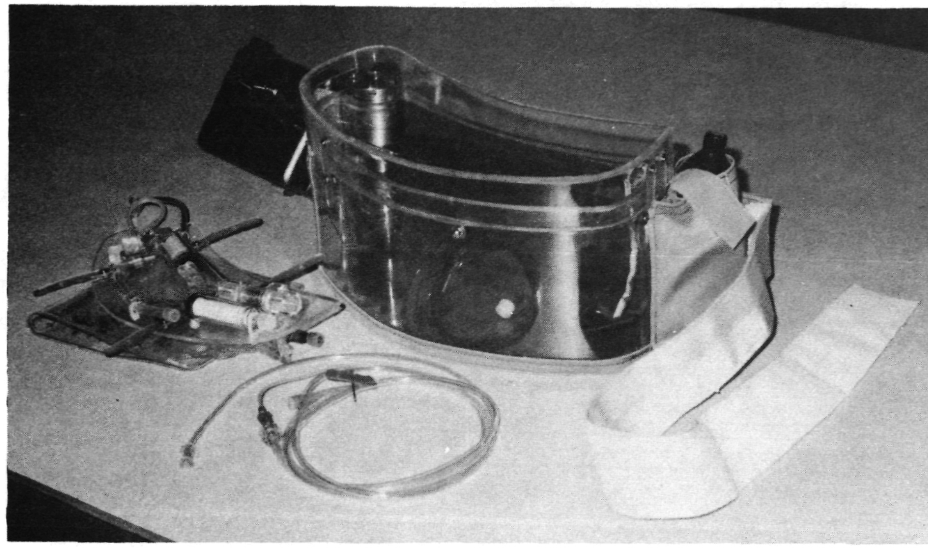
The JSC Toxicology Laboratory has the overall responsibility for ensuring that the Orbiter's crew environment is toxicologically safe. During the report period, the analyses of cabin atmospheric sample and spacecraft molecule off-gassing tests were performed. In addition, a solid sorbent air sampler was designed and initial evaluation has begun.

A space microgravity intravenous fluid infusion system was designed and developed at JSC, primarily for use in microgravity. It is not gravity

dependent and is small enough to be worn by an individual, yet capable of accepting water from the spacecraft water dispensing system and converting it to a fluid that can be safely ingested intravenously. The system is highly flexible, safe, and simple to use. One-g testing has indicated that the system meets all design requirements. Additional work is just beginning onboard NASA's KC-135 zero-g parabolic aircraft.

A prime NASA goal is to demonstrate means of using the space environment to the benefit of man on Earth. Toward that end, such products as biological compounds with pharmaceutical value are being examined. The continuous flow electrophoresis system (CFES) is being used to separate heterogeneous mixtures of human embryonic kidney cells into homogeneous fractions, some of which are useful in treating human-produced disease.

The bioreactor development project has recently added a microprocessor/computer system to the JSC prototype for control and data analysis. The effort has been extended to include research at two major universities which are developing state-of-the-art technology and equipment for commercial culture of cells to obtain pharmaceutical products. Appropriate new technology is being combined with the current bioreactor designs and tested to determine the specific features that must be included in the fabrication of a bioreactor designed to operate for STS demonstration tests. Considerations include (1) circulation and resupply of culture media; (2) sensors required to monitor temperature, cell growth, mass transport, and oxygen consumption; and (3) in-flight control of shear stress on cells, gas transfer in microgravity, diffusion, and intracellular transport. These data and results from the JSC prototype bioreactor test will be used for the design and construction of a small space bioreactor for the Orbiter middeck. The middeck bioreactor will consist of a small version of the culture vessel and related control systems. It will be certified for a flight verification test in 1986 to demonstrate systems operation and improvements or limitations in microgravity, and to obtain baseline flight data for future full-scale flight experiments.



The IV fluid system with the fluid administration plate removed.

Physician test of zero-g intravenous infusion system developed for in-flight medical treatment being performed in the NASA KC-135 zero-g aircraft.

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Significant Tasks

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Shuttle Echocardiography

TM: Michael W. Bungo/SD3
Reference OSSA 11

Exposure to weightlessness produces several adaptive phenomena in human physiology. One of the more pronounced changes occurs in the cardiovascular system. Intravascular volume moves from the lower extremities to a central and cephalad position because of relief from the hydrostatic pressure gradients imposed by gravity. To some degree, interstitial volume responds in a similar manner. From bed-rest studies, used as a simulation of microgravity, transient increases in right heart pressures, pulmonary vascular congestion, subsequent left heart dilatation, and renal diuresis have all been observed. The hemodynamic factors during space flight remain largely uncategorized.

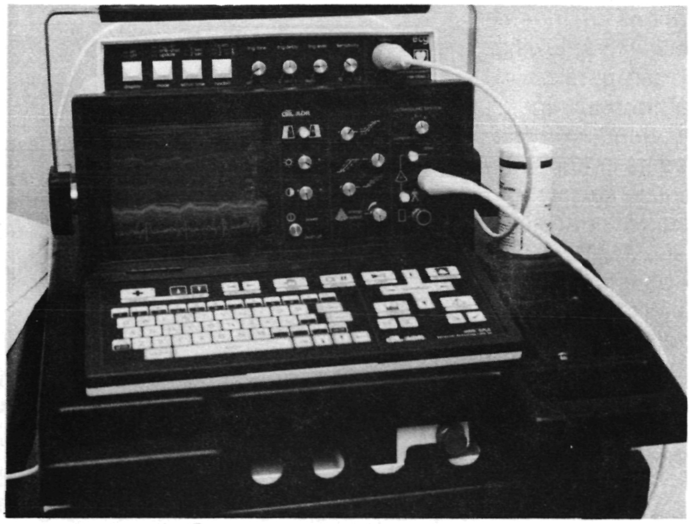
From Skylab experiments, it was documented that volume depletion did occur and that heart size was indeed reduced after flight. This decrease in intracardiac volume is accompanied by several other changes in the cardiovascular system's regulating mechanisms. The end result is a greater susceptibility to orthostatic stress. Even the simple stress of standing has produced syncope (fainting) in many returning Space Shuttle crewmembers.

To better understand and quantitate the physiologic alterations produced in the heart during space flight, echocardiographic examination of Space Shuttle crewmembers was instituted during the last year. A commercially available ultrasound scanner was employed in standard clinical fashion, and preflight and postflight real-time cardiac sector scans were obtained by JSC on crewmembers.

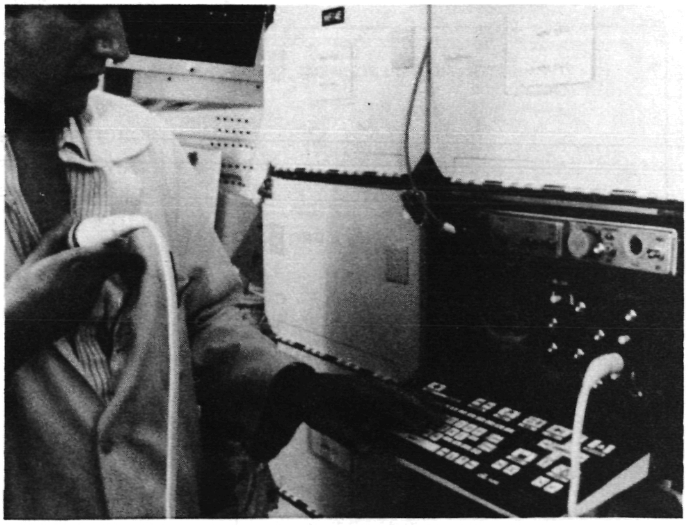
A 23% decrease in the end diastolic volume of the heart was noted immediately after flight with an equivalent loss of stroke volume. Resting heart rate and systemic vascular resistance increased 30%. A week after flight, diastolic volume remained 11% below preflight values, and 12% of the crewmembers exhibited syncope or presyncope in the period immediately after flight.

It is planned to expand this data acquisition to include in-flight parameters and to use these findings in deriving therapeutic or prophylactic adjuvants for cardiovascular deconditioning. A flight echocardiograph is ready for a mission in early 1985.

The ground unit used for development of the American flight echocardiograph.



The principal investigator for the American flight echocardiograph demonstrates use of the unit to collect cardiac data in flight on the Space Shuttle middeck.

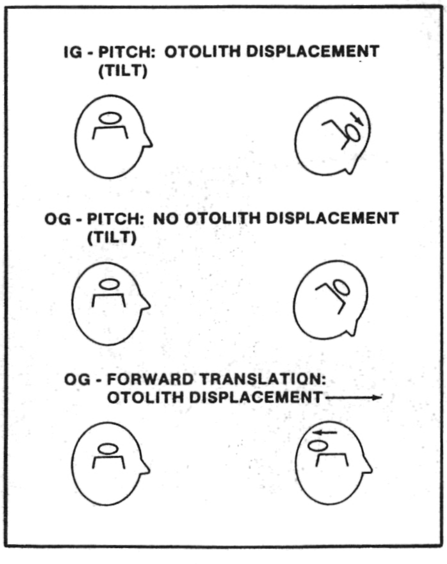


Space Adaptation Syndrome Parallel Swing Tests

TM: Jerry L. Homick/SB
Reference OSSA 12

Approximately half of all space travelers experience medical symptoms of motion sickness and spatial disorientation during the first few days of flight. The sensory conflict theory of space motion sickness suggests that adaptation by the brain to conflicting or unexpected sensory information is the cause. In weightless space flight, the greatest source of conflicting sensory information is the absence of normal Earth gravity acting on the gravity-sensitive otolith organs of the inner ear. The process of adaptation to rearrangement of stimuli in weightlessness appears to involve alterations of otolith receptor signals and of the integration of otolith signals with signals from other spatial orientation receptors. Return to a "normal" stimulus environment following prolonged exposure to rearranged stimulation is associated with a period of readaptation. Responses measured during readaptation should suggest mechanisms of response change during the initial adaptation to the rearrangement.

Otolith response to tilt and linear translation in one g and zero g.

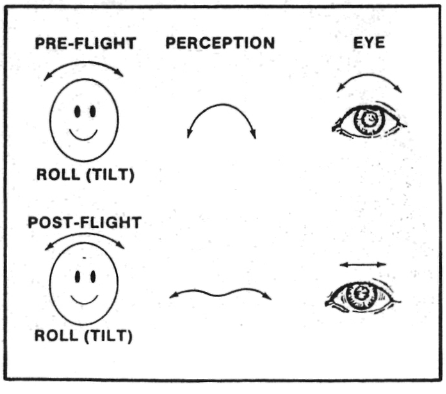


A Detailed Supplementary Objective was implemented with the STS-8 and STS-11 missions to compare immediate postflight responses to linear and angular acceleration with those obtained before flight. Three types of responses were measured: linear self-motion detection thresholds, perceived self-motion path, and eye movements. The apparatus used was the parallel swing. This device is a four-pole pendulum that produces "linear" and/or angular (roll) oscillation at a frequency of 0.26 Hz. The subject was restrained in a prone position, with head dorsal-flexed 45°. Eye movements were monitored with a video camera and an infrared light source. The camera output was recorded with a video cassette recorder.

Data obtained from three astronauts yielded two major findings. First, perceived self-motion during sinusoidal roll differed immediately after flight from preflight values. Between 70 min and 2.5 hr after landing, roll was perceived primarily as linear translation. Second, observations with two astronauts indicated that more horizontal eye movement was produced during roll immediately after flight relative to both preflight and later postflight observations. These observations support an "otolith tilt-translation reinterpretation" hypothesis. On Earth, information from the otolith receptors is used by the brain to signal body/head tilt with respect to gravity and linear motion. During extended exposure to weightlessness, the brain adapts by interpreting all otolith receptor output as linear motion (because tilt interpretations are meaningless in zero g). Immediately following return to Earth, the brain persists in interpreting otolith output as linear motion. Consequently, head/body tilt during roll is perceived as linear self-motion and results in horizontal rotation of the eyes. Changes in linear self-motion detection thresholds after flight varied with astronaut observers. One astronaut exhibited a large threshold increase, and the other two exhibited essentially no alteration in thresholds immediately after flight.

The observations made on the STS-8 and STS-11 missions have significant implications for understanding the disorientation and other symptoms that often occur during the initial exposure to weightlessness. By capitalizing on these and other relevant data, procedures and apparatus for prophylactic adaptation training (PAT) have been proposed. The proposed training is based on the concept that the brain can be forced on Earth to "recalibrate" relationships between otolith and visual signals in a manner that would be appropriate to weightlessness. In other words, eye movement reflexes, postural muscle reflexes, and self-motion experiences in relationship to visual scene movements would be appropriate to the weightlessness-adapted state. It is hypothesized that PAT would afford astronauts significant relief from space-motion-sickness symptoms during the early phase of orbital flight. Additional ground-based and flight data collections for refining the PAT concept are planned.

Postflight self-motion perception and eye movement changes.



Middeck Rotator for In-Flight Vestibular Research

TM: Millard F. Reschke/SB
Reference OSSA 13

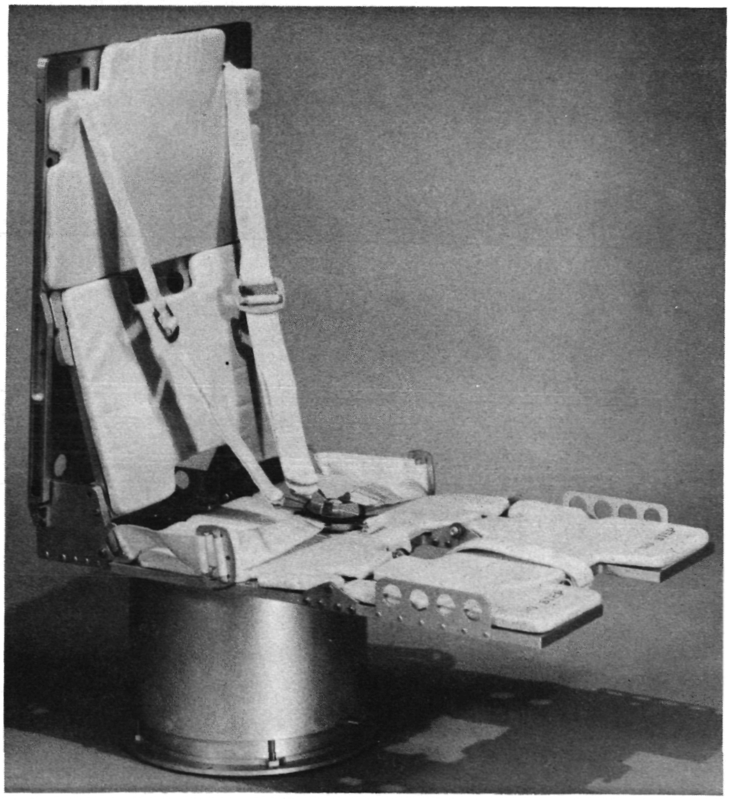
The vestibular system is important in the ability of an individual to move about and to maintain a stable orientation in relation to his surroundings. The system is composed of the otolith receptors, which are responsive to linear acceleration including the force of gravity, and the semicircular canals, which are responsive to angular acceleration. These two sensory receptors function in an interactive mode with the otoliths having the capability to modulate neural activity of the semicircular canals.

On Earth, there is a very precise relationship between movements of the head and eyes. Much of the control of eye position is dependent on vestibulo-ocular reflexes. Malfunctioning of the vestibulo-ocular reflexes during head movements may lead to disorientation and symptoms of motion sickness. On the basis of experiments performed during parabolic flight, it is known that the vestibulo-ocular reflex is affected by changes in gravitoinertial force levels. Precise characterization of vestibulo-ocular reflex changes during prolonged microgravity flight would have significance for understanding and for treating space motion sickness.

Rotating devices which permit precisely controlled angular acceleration stimuli have been the most frequently used tool to investigate vestibulo-ocular reflexes. Thus, to extend knowledge of the effects of space flight on vestibular system function, JSC is developing a rotator for the Space Shuttle Orbiter middeck. The middeck rotator will consist of a servocontrolled rotating chair/pedestal assembly and a manually operated programmable control console to vary the rotational velocity and acceleration of the chair. The lightweight motor and chair/pedestal assembly will be mounted on the forward bulkhead of the middeck and is designed so that, when not in use, it can be stowed in two middeck lockers. The system will be capable of generating constant velocity, ramp, sinusoidal, and pseudorandom profiles with angular velocities as great as 360 deg/sec and angular accelerations as great as 344 deg/sec^2.

Two flight-qualified middeck rotator systems are scheduled for completion by the end of 1984. Requirements for peripheral hardware devices for the measurement and recording of vestibulo-ocular reflexes are being defined. Laboratory studies are under way at JSC to refine experiment protocols for the first in-flight use of the middeck rotator. A major experiment proposal for the use of this device has been developed, and other proposals are anticipated. The middeck rotator should become a major tool for in-flight vestibular research.

Middeck rotator chair/pedestal assembly.



New Drug Treatment for Motion Sickness

TM: Joseph C. Degioanni/SD3 and Nitza M. Cintron-Trevino/SD3
Reference OSSA 14

Mild to severe motion sickness may occur during space flight. Typically, when a person is experiencing nausea or vomiting, oral medications are ineffective in counteracting motion sickness. Administration of anti-motion-sickness drugs by alternative methods becomes the next line of defense. The administration of drugs by injection or in the form of suppositories, however, may introduce significantly more potent side effects such as drowsiness and lack of coordination. Furthermore, drug administration by such means may be operationally or personally inconvenient. Thus, it is important to identify and validate new administration routes by which undesirable side effects are reduced by eliminating unnecessarily high dosage concentrations while maintaining reliable therapeutic levels.

The JSC and Forest Laboratories have collaborated over the past 3 yr in the development of such a drug using the buccal Synchron tablet. Forest Laboratories has successfully developed buccal Synchron preparations of nitroglycerin and morphine. Synchron products are applied directly to the buccal mucosa and are not ingested or given parenterally. Typically, they are rapidly absorbed and have predictable plasma dose/ response curves. Recently, a Synchron scopolamine tablet of 1.0 mg has been developed. This tablet has a reliable dissolution rate of 50% over 30 min in vitro.

In principle, a significant advantage of the buccal scopolamine preparation is that the drug can be removed from the gum when therapeutic blood levels are achieved and before unnecessarily high concentrations are produced. This property is particularly important in using a potent anticholinergic drug such as scopolamine, which has the propensity for producing a spectrum of well-known undesirable side effects at high levels. The results of preliminary clinical trials using a scopolamine assay developed at the JSC Biochemistry Research Laboratory indicate that scopolamine plasma levels below 200 pg/ml are relatively symptom free. New buccal preparations including prochlorperazine and other products may be of value in the prevention as well as in the acute intervention of motion sickness symptomatology. Further clinical trials are scheduled to determine whether such levels are also efficient in controlling symptoms of motion sickness.

Performing chromatographic analysis of the scopolamine content of tablets.

Conducting radioreceptor assay for scopolamine in plasma.

In Vivo Magnetic Resonance Imaging

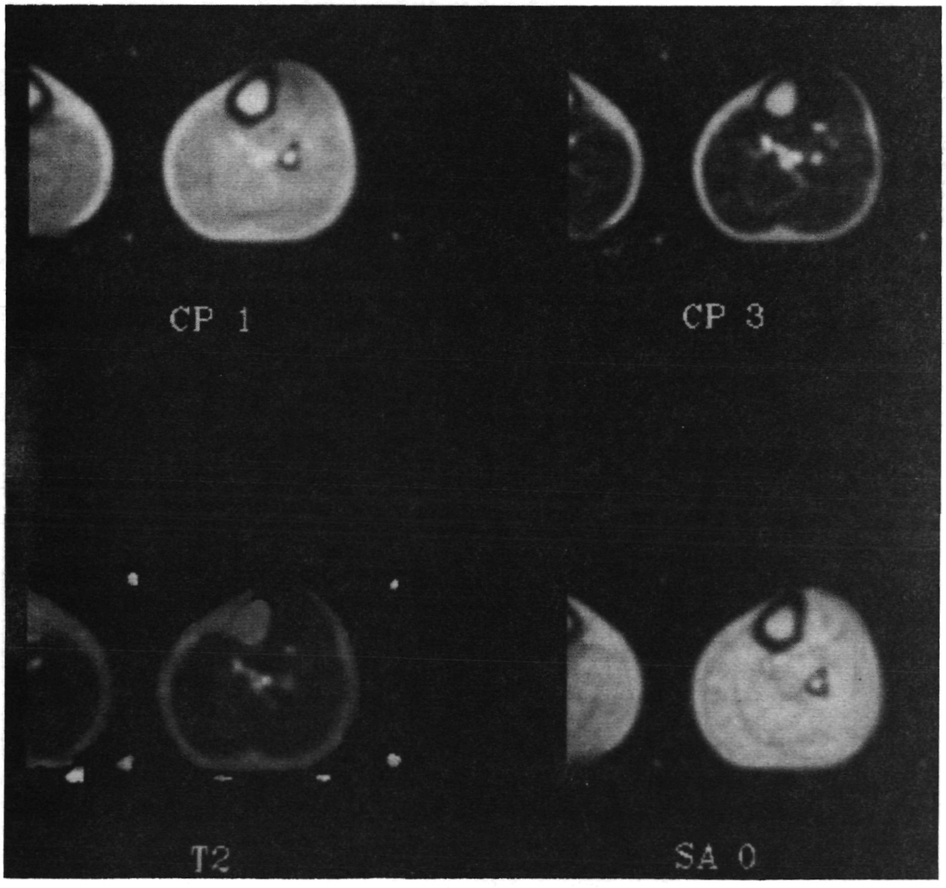
TM: Philip C. Johnson/SD3
PI: Adrian D. LeBlanc/SD3
Reference OSSA 15

A number of physiological changes have been demonstrated in bone, muscle, and blood after exposure of humans and animals to microgravity. The determination of mechanisms of change and the development of effective countermeasures for long-duration space missions is an important NASA goal. Historically, NASA has had to rely on tape measurements, x-ray exposures, and metabolic balance studies together with collection of excreta and blood specimens to obtain this information. The advent of tomographic nuclear magnetic resonance imaging (NMR or MRI) could greatly extend these early studies in ways not previously possible; NMR is also noninvasive and safe (i.e., no radiation exposure). The NMR process provides both superb anatomical images for volume measurements of individual structure and quantification of chemical and physical changes induced in the examined tissues.

The current work at JSC and the Baylor College of Medicine has been funded with seed money from the JSC Center Director Discretionary Fund. Studies to date have focused on proton imaging of the limbs of bed-rest subjects to simulate a microgravity environment. An improved method for producing images calculated from T2 relaxation times has been developed. A computer scheme for classifying tissue according to different T2 relaxation times and quantifying tissue volumes has also been implemented. To date, six subjects have been imaged before and after 5 weeks of bed rest. On the basis of cross-sectional images through the lower leg, the gastrocnemius and soleus muscle areas decreased by 9%, whereas the total muscle area in this same section decreased only 6%, a demonstration of differential muscle loss. Bone marrow T2 decrease of 14% ($p < 0.001$) after bed rest indicates an increase in bone marrow fat. This change may be related to red cell mass and bone changes observed after exposure to weightlessness and bed rest. Muscle T2 did not change, a suggestion that tissue hydration is not changed by atrophy.

The currently employed limb measurements will be extended to the back muscles and the spine in the future. Future studies will also include measurement of fluid shift, intracellular vs. extracellular fluid, high-energy phosphate metabolism, and blood flow as these techniques are developed and defined in the bed-rest studies.

NMR cross-sectional imaging through lower limb of volunteer. The first two images were obtained during the early (CP1) and late (CP3) portions of the spin echo train. The second two are calculated images of T2 and spin density (SAO).



Detection of Incipient Altitude Decompression Sickness With Doppler Sensors in Flight

TM: James M. Waligora/SD3 and David J. Horrigan/SD3
PI: James R. Jauchem/SD3 and John Conkin/SD3
Reference OSSA 16

The change in pressure from the Space Shuttle cabin (14.7 psi) to that of the extravehicular activity (EVA) suit (4.3 psi) is great enough to cause symptoms of bends. Doppler bubble detectors continue to be used to detect presymptomatic nitrogen bubbles in the pulmonary artery. A bends prevention procedure was developed for the current Space Shuttle EVA on the basis of data obtained with this instrumentation. However, a question remained as to future use of multiple EVA's on the same day and for several days in succession. Testing was done at JSC in June 1984 to help answer this question.

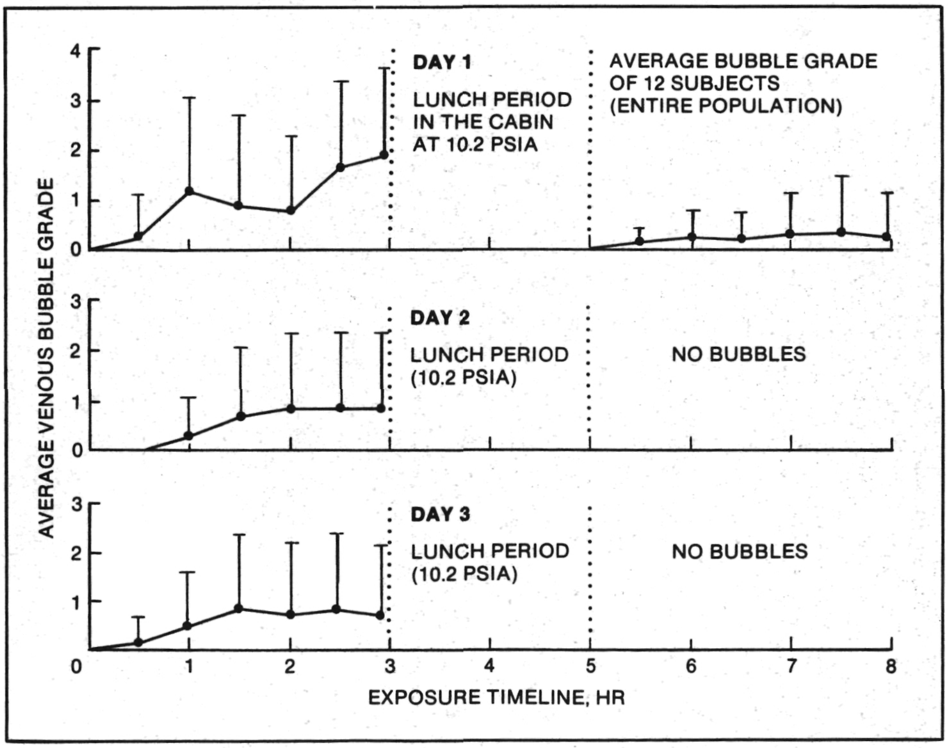
The test involved a 3-day exposure of 12 subjects to a protocol of 2 simulated EVA's per day. Subjects were exposed to the protocol in groups of three. After 1 hr of conditioning at 14.7 psia, the pressure in the test chamber was reduced to 10.2 psi and oxygen (O_2) enriched to 26.5% for a 12-hr period. The subjects then donned O_2 masks and breathed 100% O_2 for 40 min prior to reduction of the chamber pressure to 4.3 psia. The subjects then worked at EVA-representative tasks for a 3-hr period. After the work period, the chamber pressure was returned to 10.2 psia and the masks were doffed. The subjects then ate lunch. At 80 min into the break, they donned the masks again and breathed O_2 for another prescribed 40 min. The subjects then engaged in a second 3-hr work period at a pressure of 4.3 psi and were returned to 10.2 psi for the overnight period. This same routine was repeated on the second and third days.

Only one incidence of decompression sickness occurred during the test series, on the first EVA simulated exposure of the first day. There were no symptoms during any of the other exposures.

Venous bubbles were monitored using a Doppler bubble detector. Bubble incidence on the first runs of the day was 58% on the first day, 33% on the second day, and 33% on the third day. Bubble incidence of the second work period of the day was 17% on the first day, 0% on the second day, and 0% on the third day. The average bubble grade is illustrated as a function of time. These tests also indicated that when this decompression profile is followed, small but significant changes occur in several blood biochemical parameters and that measurement of certain blood factors may help to predict susceptibility to venous gas emboli formation during decompression.

The studies again illustrated the usefulness of ultrasonic technology in evaluating physiological reactions to a changing environment. Work is continuing in the development of an instrument to be placed inside a suit. The objective is to develop an instrument which will accommodate some movement of the heart in the chest wall and still detect adequate bubble sounds.

Bubble grades based on frequency of bubbles detected by ultrasonic Doppler instrumentation. Six periods of exercise of 3 hr each were scheduled at 4.3 psia during a 3-day exposure.



Use of ultrasonic Doppler sensor to detect intravenous gas bubbles in a hypobaric environment.

Cell Culture in Microgravity and Development of a Space Bioreactor

TM: Dennis R. Morrison/SD4
Reference OSSA 17

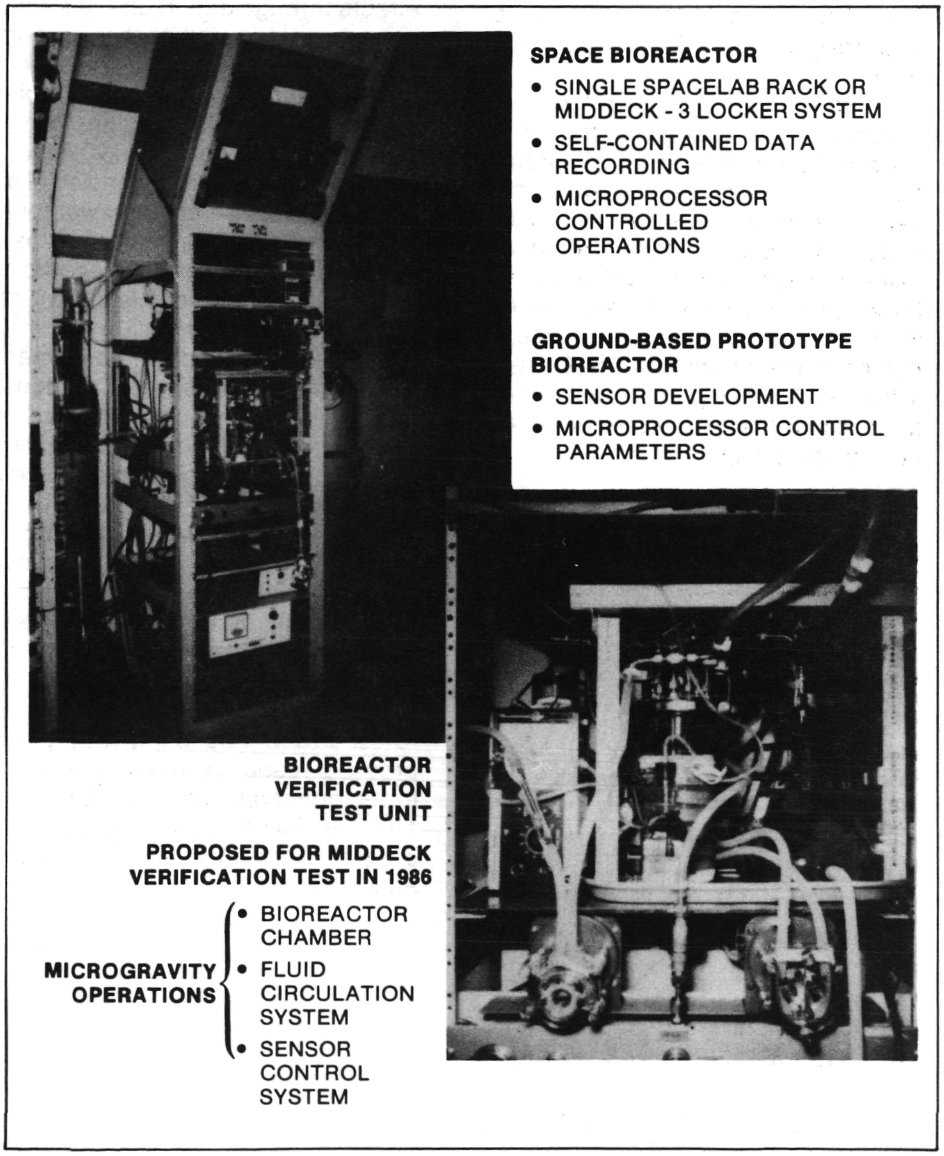
The NASA is chartered to demonstrate the potential of microgravity for the improved processing of useful products such as biological compounds with pharmaceutical value. For example, JSC has used McDonnell-Douglas Aerospace Corporation's continuous flow electrophoresis system (CFES) to separate heterogeneous mixtures of human embryonic kidney cells into about 30 electrophoretically different fractions containing plasminogen activators, which are useful in treating blood-clot-related diseases. The goal of the program is to demonstrate that useful cells from a variety of heterogeneous mixtures can be better separated and cultured in space and their biological products collected and purified. To achieve this goal, methods and equipment are being developed for culturing and handling cell cultures in microgravity.

Normal human cells require attachment to a suitable surface and special culture conditions to grow. These requirements are modified and amplified when cells are taken into a weightless environment. Methods have been developed to maintain cells in special incubators designed for the Orbiter middeck; however, electrophoresis and other experiments require that cells be harvested before they can be processed or used. Experience with the cell transport assembly (CTA) flown on STS-8 indicates that the CTA must be improved so that adequate numbers of cells can be maintained for longer than 48 hr. In addition, harvested cells must be concentrated from wash fluids before they can be used or recultured. The life sciences middeck centrifuge could be modified to enable transfer of cells from the CTA with maintenance of cell sterility. The optimum in-flight procedures and timelines must be determined, then incorporated into the design and construction of an advanced CTA which can be used to supply living cells for future CFES and other cell flight experiments.

In addition, after electrophoresis separation or other bioprocessing, the cells must reattach to a suitable surface before they can grow again. The STS-8 cell attachment test indicated that microcarrier beads can be used for stabilizing cells if they are incubated at a temperature of 37°C. Better in-flight methods are being developed.

For larger scale culture of cells and collection of biological products, microgravity offers significant promise. In normal gravity conditions, commercial culture of mammalian cells to produce pharmaceutical products is compromised by sedimentation and inadequate transfer of gaseous oxygen. The shear forces, accompanying the stirring required to keep microcarriers (with cells attached) suspended, and oxygenation can damage cells severely. Some U.S. and European flight experiments indicate possible increases in growth rate and cell size of eucaryotic cells grown under weightless conditions. Microgravity has potential for improved mass culture of mammalian cells. Conversely, in microgravity, one cannot rely on head space (air above the liquid phase) to assist in the oxygen supply. A bioreactor optimized for operations in space is being developed by JSC. The current research is focused on determining the optimum cell-to-bead ratios, medium content, and proper maintenance conditions required to keep living cell specimens alive and healthy for the entire flight while using fluid handling subsystems designed to operate in microgravity.

Space bioreactor for cell cultures.



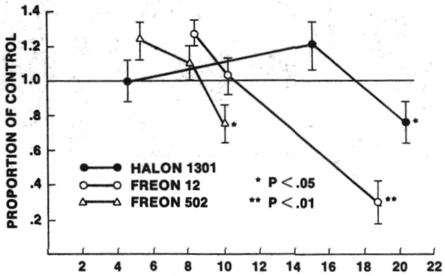
Toxic Hazard Assessments in the STS Program

TM: Duane L. Pierson/SD4
PI: Dane Russo/SD4
Reference OSSA 18

The JSC Toxicology Laboratory has the overall responsibility for ensuring that the Space Shuttle crew environment is toxicologically safe. Achievement of this objective requires the identification of all potential spacecraft contaminants through the analysis of cabin atmospheric sample and spacecraft material off-gassing tests. Once a compound has been identified as a potential contaminant, a spacecraft maximum allowable concentration (MAC) must be established for that compound. Establishing an MAC value involves consideration not only of crew health, but also of the more subtle behavioral effects which may result from exposure to the compound and adversely affect crew performance.

In many cases, an abundance of information is available about the toxicity of a compound. This information, together with the threshold limit values used as industrial standards, is considered when setting an MAC value for each contaminant. In cases for which there is insufficient toxicity information or industrial experience, a number of toxicity tests are performed in the JSC Toxicology Testing Laboratory to define the toxic hazard associated with the compound.

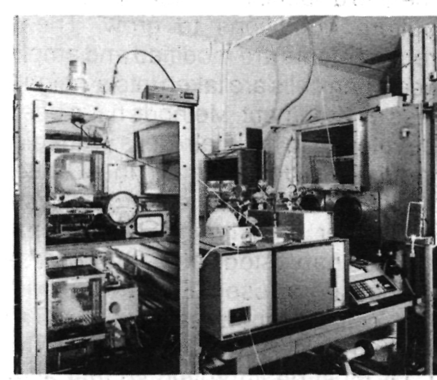
Mean (plus or minus standard error) 2-hr response rates during tests of three different concentrations of Halon 1301, Freon 12, and Freon 502.



Some of the compounds identified as potential spacecraft contaminants may be classified as sensory irritants (i.e., compounds which evoke a burning sensation in the eyes, nose, and throat of an exposed individual). A decrease in the respiratory rate due to a pause in the expiratory phase of respiration is one of the physiological reflexes induced by a sensory irritant. For testing the irritancy of these airborne contaminants, a head-only animal exposure system is used to measure chemically induced changes in the respiration rate of test subjects. The irritant properties of contaminants may be established by comparing the concentrations of compounds which induce a 50% decrease in the respiratory rate of test animals. This 50% rate has been shown to be a predictable indicator of sensory irritancy in man.

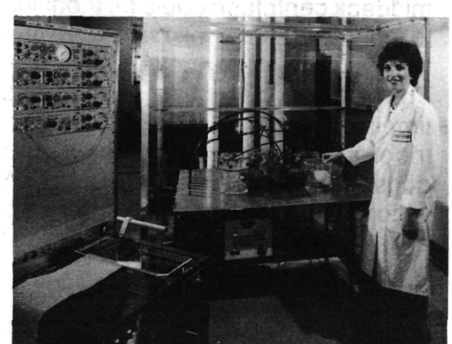
Compounds which produce toxic effects through action on the central nervous system rather than through sensory irritancy are tested with a battery of behavioral tests, which include measures ranging from a change in general activity level to changes in operant behavior. This application of operant behavior technology to behavioral toxicology is a relatively recent innovation. According to the operant protocol used, rodents are trained to depress a lever to receive liquid food reinforcement. Once an animal's operant response has stabilized, the contaminant being tested is introduced into the test chamber until a predetermined concentration is reached. The compound's effect on response is then determined by comparing test session response rates with control rates. The pattern of effects found during operant tests of three potential spacecraft contaminants is illustrated. Test rates are expressed as a proportion of control rates. Freon 502 significantly depressed response rates at a much lower concentration than did Halon 1301 or Freon 12, an indication of greater behavioral activity for the Freon 502.

A research program using these techniques is under way to assess the toxic hazard of multiple spacecraft contaminants. The information generated in the STS Toxic Hazard Assessment Program is also of interest to the scientific and industrial communities where concerns exist for worker health and safety. These continued studies should substantially add to our understanding of the mechanisms of toxic activity.



Inhalation chambers used to test the behavioral toxicity of spacecraft contaminants.

Head-only chambers used for testing the irritant properties of spacecraft contaminants.



Design and Evaluation of a Solid Sorbent Air Sampler

TM: Duane L. Pierson/SD4
PI: Theodore J. Galen/SD4
Reference OSSA 19

Monitoring of the Space Shuttle cabin atmosphere is a major responsibility of the Toxicology Laboratory at JSC. The toxicological monitoring of the Orbiter crew cabin is focused on the breathing atmosphere. The presence of trace amounts (1 p/m or less) of volatile compounds in a closed environmental control and life support system can result in the exposure of the flightcrew to such compounds. The toxicity of some volatile contaminants may adversely affect specific physiological parameters and the efficiency of the crewmembers. Therefore, it is essential to monitor the spacecraft atmosphere before and during flight to determine the levels of these contaminants.

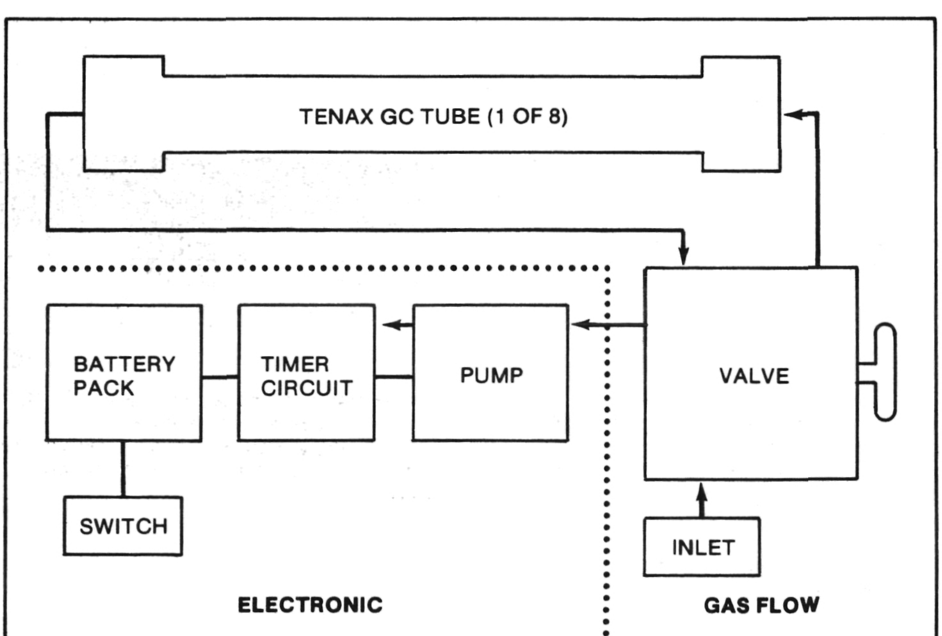
Historically, monitoring of the spacecraft atmosphere has consisted of collecting air samples in evacuated cylinders. This static sampling process yields analytical information of the cabin air only at the time the cylinder valve is opened and the sample is instantaneously collected.

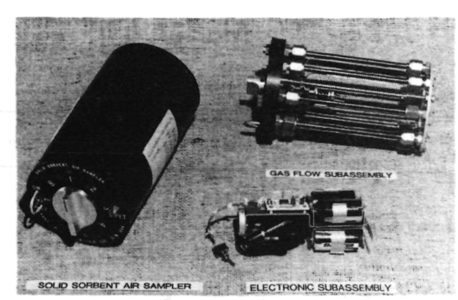
The solid sorbent air sampler was developed to collect gaseous contaminants continually over a 24-hr period and to repeat the cycle for as many as 8 days. This method, in which a solid material (Tenax GC) is used to adsorb the trace-level organic compounds, has several inherent advantages. First, with the proper selection of solid sorbent material, the trace volatile organic compounds can be concentrated while oxygen and nitrogen, the major volume components of the sample, are not retained. Second, the method is applicable to multiple, continuous, and automated operation. Finally, the increase in size and weight is minimal when multiple samples are collected.

The solid sorbent air sampler is 4.5 in. in diameter and 9.5 in. long, and it weighs approximately 4 lb. It is totally self-contained and, thus, requires neither spacecraft power nor vacuum. An electronic subassembly precisely controls the sample flow rate by using a timer circuit to pulse the pump motor on and off at a set frequency. The gas flow subassembly, which is built around the microvalve, transports the sample to the appropriate Tenax GC tube. These two subassemblies contain the major components of the sampler. The solid sorbent air sampler can be operated in any orientation within the area to be sampled. On completion of a mission, the solid sorbent air sampler will be transferred to the laboratory for analysis of the adsorbed compounds.

Two developmental prototypes and four flight units of the solid sorbent air sampler have been fabricated. Certification of the flight units is currently in progress, and the first unit is scheduled to be flown on the STS 51-B mission. The solid sorbent air sampler has been extensively tested both in the laboratory and in simulations. Within the scope of its design capabilities, its performance has been to specifications.

Schematic of the solid sorbent air sampler electronic and gas flow subassemblies. Arrows indicate the flow of an air sample through the sampler.





Solid sorbent air sampler and subassemblies.

Space Microgravity Intravenous Infusion System

TM: James S. Logan/SD2
PI: Fred A. Brown/SB
Reference OSSA 20

A need has existed for an intravenous (IV) infusion system that is independent of gravity, small enough to be worn by an individual, and capable of accepting water from the spacecraft water dispensing system. No existing commercial system met these requirements.

The design specifications for the infusion system included precise control of normal IV flow rates (40, 75, 125, and 200 cm^3/hr) and the capability to provide higher flow rates (as high as 1000 cm^3/hr) in response to a life-threatening medical emergency. To meet these requirements, a space microgravity IV fluid infusion system has been designed and developed in the JSC Life Sciences Laboratory.

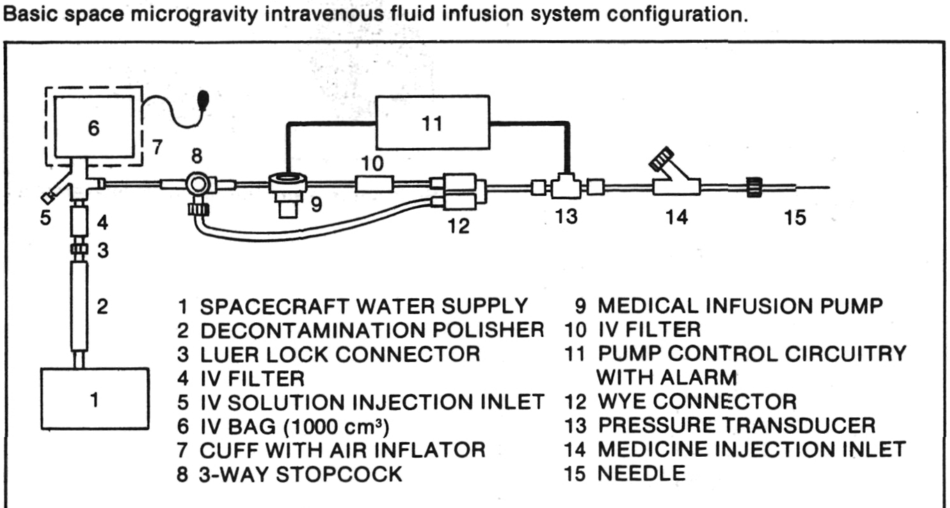
The developed administration tubing set incorporates a three-way stopcock to enable selection of different application modes and two 0.22-μm IV filters to assure patient safety from air emboli. With its main portion mounted on a small clear-plastic plate, the unit is mostly constructed from modified off-the-shelf components. It is sterilized to Food and Drug Administration standards, packaged, and used as a disposable item for contamination control.

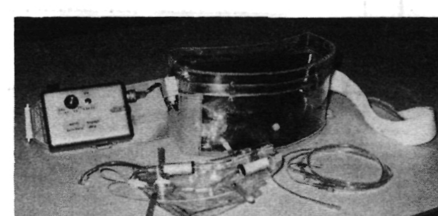
Carrying bags of IV fluid into space is not practical because of their potentially high weight and bulky size. To overcome this problem, IV fluid will be produced in space from the Orbiter water supply. Water is forced through a specially designed decontamination polisher and then through an air filter. The sterile water is then mixed with a concentrated IV solution and flows into a 1000-cm^3 reservoir IV bag. Crewmembers can prefill a certain number of bags by this method while in orbit. In packaging the system, both volume and weight are minimized. The system's final physical configuration also incorporates patient mobility considerations.

The system is highly flexible, safe, and simple to use. Prior testing (on Earth) has proved that it meets all design requirements. Detailed human testing will be conducted both in the laboratory and onboard the NASA KC-135 zero-g parabolic aircraft.

The system has many advantages over most commercially available IV devices. It is expected that this ambulatory IV infusion system will gain acceptance in the medical field and will be widely used in the hospital environment in the near future.

Basic space microgravity intravenous fluid infusion system configuration.





Photograph of the space microgravity intravenous infusion system showing, from left to right, the electronic control box, and the administration plate in the system carrying case.

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Reference Number	Significant Task
	Office of Space Flight
OSF 1	**Orbital Refueling System Development** Funded by: Advanced Development (UPN-906) Technical Monitor: Harold E. Benson/EX Task Performed by: Lyndon B. Johnson Space Center
OSF 2	**Satellite Services System** Funded by: Advanced Development (UPN-906) Technical Monitor: Gordon Rysavy/EX Task Performed by: Science Applications, Inc., Contract NAS 9-17207
OSF 3	**Telepresence Work System Definition Study** Funded by: Advanced Development (UPN-906) Technical Monitor: Lyle M. Jenkins/EX Task Performed by: Grumman Aerospace Corporation Contract NAS 9-17229 Martin Marietta Aerospace Corporation Contract NAS 9-17230
OSF 4	**Advanced Rendezvous and Docking Sensor** Funded by: Advanced Development (UPN-906) Technical Monitor: Harry O. Erwin/EE6 Task Performed by: Lyndon B. Johnson Space Center
OSF 5	**STS Propellant Scavenging** Funded by: Advanced Development (UPN-906) Technical Monitor: Gene R. Grush/EP4 Task Performed by: Rockwell International Corporation Contract NAS 9-16994
OSF 6	**8.0-psi Space Suit** Funded by: Advanced Development (UPN-906) Technical Monitor: Joseph J. Kosmo/EC5 Task Performed by: Hamilton Standard Contract NAS 9-15150
OSF 7	**Remote Manipulator System Control Technology** Funded by: Advanced Development (UPN-906) Technical Monitor: Henry J. G. Kaupp, Jr./EH2 Task Performed by: C. S. Draper Laboratory, Inc., Contract NAS 9-16023
OSF 8	**Tethered Orbital Refueling** Funded by: Advanced Development (UPN-906) Technical Monitor: Kenneth R. Kroll/EP4 Task Performed by: Martin Marietta Aerospace Corporation Contract NAS 9-17059
OSF 9	**Electrodynamic Tethers** Funded by: Advanced Development (UPN-906) Technical Monitor: James E. McCoy/SN3 Task Performed by: Lyndon B. Johnson Space Center
OSF 10	**Orbital Debris** Funded by: Advanced Development (UPN-906) Technical Monitor: Donald J. Kessler/SN3 Task Performed by: Lyndon B. Johnson Space Center

Reference Number	Significant Task

Office of Aeronautics and Space Technology

OAST 1 **Advanced Manned Vehicle Onboard Propulsion Technology**
Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: William C. Boyd/EP4
Task Performed by: Aerojet TechSystems Company Contract NAS 9-16639

OAST 2 **Low-Earth-Orbit Energy Storage Using Regenerative Fuel Cells**
Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: J. Dale Denais/EP5
Task Performed by: General Electric Company Contract NAS 9-15831
Life Systems, Inc., Contract NAS 9-16659

OAST 3 **STS Guidance and Control**
Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: Paul C. Kramer/EH2
Task Performed by: Charles Stark Draper Laboratory Incorporated Contract NAS 9-16023
TRW, Inc., Contracts NAS 9-17011 and NAS 9-16928

OAST 4 **Man-Modeling of Human Factors for Crew Interfaces in Space**
Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: Barbara Woolford/SP22
Task Performed by: University of Pennsylvania Contracts NAS 9-17003 and NAS 9-19934

OAST 5 **Multifunction Synthetic Aperture Radar Technology**
Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: Kumar Krishen/EE4
Task Performed by: Lyndon B. Johnson Space Center

OAST 6 **Magnetic Bubble Memory System Development**
Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: Edgar A. Dalke/EH4
Task Performed by: Lockheed Engineering Management and Technical Services Company, Inc., Contract NAS 9-15800

OAST 7 **Space Station Communication and Tracking Technology**
Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: Kumar Krishen/EE4
Task Performed by: Lyndon B. Johnson Space Center

OAST 8 **Orbiter Experiments Integrated Systems Test**
Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: R. L. Spann/EX3
Task Performed by: Lyndon B. Johnson Space Center

OAST 9 **Atomic Oxygen Interaction Studies**
Funded by: Space Research and Technology Base (UPN-506)
Technical Monitors: L. J. Leger/ES5 and J. T. Visentine/ES5
Task Performed by: Lyndon B. Johnson Space Center

OAST 10 **Space-Constructable-Radiator Thermal Vacuum Test Program**
Funded by: Space Research and Technology Base (UPN-506)
Technical Monitor: Paul F. Marshall/EC2
Task Performed by: Grumman Aerospace Corporation Contract NAS 9-15965

Office of Space Sciences and Applications

Solar System Exploration

OSSA 1 **New Results for Some Old Rocks: Fra Mauro Revisited**
Funded by: Planetary Materials (UPN-152)
Principal Investigator: L. E. Nyquist/SN4
Task Performed by: Lyndon B. Johnson Space Center

OSSA 2 **Old Detrital Lunar Zircons**
Funded by: Planetary Materials (UPN-152)
Principal Investigator: Charles Meyer, Jr./SN2
Task Performed by: Lyndon B. Johnson Space Center

Reference Number	Significant Task
OSSA 3	**Experimental Regolith Studies** Funded by: Planetary Geochemistry and Geophysics (UPN-153) Principal Investigators: F. Horz/SN4 and M. J. Cintala/SN3 Task Performed by: Lyndon B. Johnson Space Center
OSSA 4	**The Antarctic Meteorite Collection** Funded by: Planetary Materials (UPN-152) Principal Investigator: John O. Annexstad/SN2 Task Performed by: Lyndon B. Johnson Space Center
OSSA 5	**Crystallization of Chondrules in Meteorites** Funded by: Planetary Geochemistry and Geophysics (UPN-153) Principal Investigator: Gary Lofgren/SN4 Task Performed by: Lyndon B. Johnson Space Center
OSSA 6	**Trace Gases in SNC Meteorites and Implications for a Martian Origin** Funded by: Planetary Materials (UPN-152) Principal Investigators: Donald Bogard/SN4 and Larry Nyquist/SN4 Task Performed by: Lyndon B. Johnson Space Center
OSSA 7	**Chronology of Ancient Terrestrial Igneous Events** Funded by: Early Crustal Genesis (UPN-153) Principal Investigators: William C. Phinney/SN4 and Don Morrison/SN4 Task Performed by: Lyndon B. Johnson Space Center
OSSA 8	**Hypervelocity Impact Studies of Composite Materials** Funded by: Advanced Programs and Plans (UPN-506) Technical Monitor: Jeanne Lee Crews/SN3 Task Performed by: Lockheed Engineering and Management Services Company Contract NAS 9-15800
OSSA 9	**Sonic Boom Studies** Funded by: Shuttle Program Office (UPN-561) and U.S. Air Force (UPN-551) Technical Monitor: John Stanley/SN3 Task Performed by: Lockheed Engineering and Management Services Company Contract NAS 9-15800
OSSA 10	**Lunar Base Planning Studies** Funded by: Office of the Chief Engineer (UPN-323) Principal Investigator: M. B. Duke/SN Task Performed by: Lyndon B. Johnson Space Center
	Life Sciences
OSSA 11	**Shuttle Echocardiography** Funded by: Life Sciences (UPN-199) Technical Monitor: Michael W. Bungo/SD3 Task Performed by: Lyndon B. Johnson Space Center Technology Incorporated Contract NAS 9-14880
OSSA 12	**Space Adaptation Syndrome — Parallel Swing Tests** Funded by: Life Sciences (UPN-199) Technical Monitor: Jerry L. Homick/SB Task Performed by: Lyndon B. Johnson Space Center Universities Space Research Association Contract NAS 9-16842
OSSA 13	**Middeck Rotator for In-Flight Vestibular Research** Funded by: Life Sciences (UPN-199) Technical Monitor: Millard F. Reschke/SB Task Performed by: Lyndon B. Johnson Space Center Universities Space Research Association Contract NAS 9-16842 Technology Incorporated Contract NAS 9-14880
OSSA 14	**New Drug Treatment for Motion Sickness** Funded by: Life Sciences (UPN-199) Technical Monitors: Joseph C. Degioanni/SD3 and Nitza M. Cintron-Trevino/SD3 Task Performed by: Lyndon B. Johnson Space Center Northrop Services Incorporated Contract NAS 9-15425

Reference Number	Significant Task
OSSA 15	**In Vivo Magnetic Resonance Imaging** Funded by: Life Sciences (UPN-199) Technical Monitor: Philip C. Johnson/SD3 Principal Investigator: Adrian D. LeBlanc/SD3 Task Performed by: Lyndon B. Johnson Space Center Baylor College of Medicine Contract NAS 9-16442
OSSA 16	**Detection of Incipient Altitude Decompression Sickness With Doppler Sensors in Flight** Funded by: Life Sciences (UPN-199) Technical Monitors: James M. Waligora/SD3 and David J. Horrigan/SD3 Principal Investigators: James R. Jauchem/SD3 and John Conkin/SD3 Task Performed by: Lyndon B. Johnson Space Center Technology Incorporated Contract NAS 9-14880
OSSA 17	**Cell Culture in Microgravity and Development of a Space Bioreactor** Funded by: Life Sciences (UPN-199) Technical Monitor: Dennis R. Morrison/SD4 Task Performed by: Lyndon B. Johnson Space Center Technology Incorporated Contract NAS 9-14880
OSSA 18	**Toxic Hazard Assessments in the STS Program** Funded by: Life Sciences (UPN-199) Technical Monitor: Duane L. Pierson/SD4 Principal Investigator: Dane Russo/SD4 Task Performed by: Lyndon B. Johnson Space Center Northrop Services Incorporated Contract NAS 9-15425
OSSA 19	**Design and Evaluation of a Solid Sorbent Air Sampler** Funded by: Life Sciences (UPN-199) Technical Monitor: Duane L. Pierson/SD4 Principal Investigator: Theodore J. Galen/SD4 Task Performed by: Lyndon B. Johnson Space Center Northrop Services Incorporated Contract NAS 9-15425
OSSA 20	**Space Microgravity Intravenous Infusion System** Funded by: Life Sciences (UPN-199) Technical Monitor: James S. Logan/SD2 Principal Investigator: Fred A. Brown/SB Task Performed by: Lyndon B. Johnson Space Center Technology Incorporated Contract NAS 9-14880

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15. Supplementary Notes

16. Abstract

Johnson Space Center accomplishments in new and advanced concepts during 1984 are highlighted. Included are research funded by the Office of Aeronautics and Space Technology; Advanced Programs tasks funded by the Office of Space Flight; and Solar System Exploration and Life Sciences research funded by the Office of Space Sciences and Applications. Summary sections describing the role of the Johnson Space Center in each program are followed by one-page descriptions of significant projects. Descriptions are suitable for external consumption, free of technical jargon, and illustrated to increase ease cf comprehension.

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